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ABSTRACT

The study reports on technical and cost factors affecting future growth of Cable TV (CATV) systems and the development of the "wired nation." Comparisons are made between alternatives for distributing CATV signals and alternative prototypes for subscriber home terminals. Multi-cable, augmented-channel (with converter), and switched CATV systems are reviewed in language aimed at informed laymen. It is concluded that within five years, a combination of 40 to 60 downstream to-the-subscriber program channels, certain video interconnect services, and substantial two-way home digital data services can be provided in several ways at reasonable cost: from $200 to $500 per subscriber, depending on the type of service, level of penetration, and costs of installing and maintaining the wiring. Appendices discuss interference problems in frequency multiplexed TV transmission over CATV, and the characteristics of two switched CATV systems. (Author/MG)

PRESENT AND PROBABLE CATV/BROADBAND-COMMUNICATION TECHNOLOGY

John E. Ward

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A Report Prepared for the
SLOAN COMMISSION ON CABLE COMMUNICATIONS

The opinions expressed herein are the views of the author and do not reflect necessarily the opinions of the members of the Sloan Commission on Cable Communications or of the Alfred P. Sloan Foundation.

ABSTRACT

This report presents the results of a study performed for the Sloan Commission on Cable Communications, the emphasis of which was on technical and cost factors affecting possible growth of present CATV system concepts over the next several decades to encompass additional "wired nation" communications functions, up to and including point-to-point videophone service. Multi-cable, augmented-channel (converter), and switched CATV systems are reviewed, both from a total channel-count viewpoint, and on the basis of two-way capabilities for video and home digital data services.

It is concluded that within the next five years, a combination of 40-60 downstream program channels, certain video interconnect service, and substantial two-way, home digital data services can be provided in several ways at reasonable cost: \$200-\$500 per subscriber, depending on the type of service and the level of penetration. Switched videophone service would also be feasible, perhaps on a national basis by the end of the century, but would escalate per-subscriber costs by a factor of at least 20 or 30, and would have to be based on a hub rather than a tree network at the subscriber level.

Appendices discuss the inter-channel interference problems in frequency-multiplexed TV transmission, and the detailed characteristics of two recently developed switched CATV systems.

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Finally, the contributions of the others at the Electronic Systems Laboratory and elsewhere at M.I.T. who participated in the study are acknowledged. Professor J. Francis Reintjes, Director of ESL, participated in a number of visits and commission meetings and provided active counsel. Professor James K. Roberge and Mr. Robert G. Rausch of ESL plus Paul J. Fox (graduate student), contributed the bulk of the material on digital technology in Chapter IV and Appendix D. Thanks are also due Professors Louis D. Smullin, Wilbur Davenport, and Peter Elias for many stimulating conversations and the reading of interim material.

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CHAPTER I

INTRODUCTION

The impetus for this report came from the Sloan Commission on Cable Communications, which felt that as part of its deliberations on the desirable future role of broadband cable networks, and how best to achieve that role, it needed a comprehensive review and evaluation of the state-of-the-art in CATV technology and expected future capabilities.

Of particular interest to the Commission in connection with such a review and evaluation were questions such as the following:

1) Should future broadband systems for home communications services be organized in frequency multiplex tree networks, as in present CATV systems, or in switched hub networks, as in the telephone system? (This question is of course related to the following ones.)

2) What are the prospects for obtaining 40, 60, or 80 program channels, and what are the respective cost expectations?

3) What home data services such as meter reading, push-button banking and/or shopping, and general computer access are (or will be) practical, and what are (or will be) the costs?

4) What is the relation of the future CATV network to the emerging Picturephone service of the Bell System, and would it make technical and economic sense to integrate them and/or replace the limited-resolution 1-MHz Picturephone service with full 4-MHz switched video service?

5) Is nationwide standardization of CATV systems in the near future a desirable or necessary condition if a nationwide broadband network is the goal?

Not all of these questions can of course be answered definitively in a short six-month study, particularly when one is trying to peer 10 or 20 years into the future in an environment of fast-paced technological evolution, and when some of the alternatives may represent a fair share of the gross national product in terms of required investment. However the study has attempted to provide the best information possible to the

Commission by thoroughly examining the underlying framework of video/ digital transmission and switching techniques applicable to combined CATV/communications services, and making estimates of future technical/ cost trends.

The major conclusions applicable to the Commission's questions are presented in the Summary; Chapter II. Chapter III investigates present techniques and probable future extensions for "high-channel-count" systems, i.e., those capable of providing 20 or more program distribution channels. Two-way video and digital data services are examined in Chapter IV.

In connection with the studies reported in Chapters III and IV, it soon became apparent that no valid comparison of the alternate techniques and the motivations behind them could be made without constant reference to the exceedingly complex inter-channel interference effects in frequency multiplexed TV channels. It was also found that a vigorous industry/ government dialog is currently under way on the question of possible CATV-system standards, which could influence the relative balance between techniques so far as these interference effects are concerned. However, no comprehensive source reference on these questions could be found. Thus to provide the necessary base for system comparisons, considerable time was devoted to the compilation, analysis and organization of available data from a variety of sources, as reported in Appendix A.

Switched CATV systems are quite new and little understood, and because of their importance in connection with the questions posed by the Commission, the two switched systems extant were examined perhaps more thoroughly than the more conventional technology and written up in interim memoranda submitted to the Commission. These are reproduced here (in corrected form) as Appendices B and C. Finally, some attention was paid to the fact that there are two other sets of wires leading into every CATV home — the telephone line and the power line — and that some efforts are under way in the direction of meter reading and possibly other data services over one or the other of these lines. Data gathered on these efforts is given in Appendix D.

CHAPTER II

SUMMARY AND CONCLUSIONS

The major conclusions summarized below are organized by topic according to the questions that were posed by the Sloan Commission on Cable Communications as the background for the study. Each topic is discussed in more detail elsewhere in the report.

Note that in the following all cost figures for cable distribution plant (including subscriber drops but not head-end equipment) are on a per-subscriber basis, and on the assumption of 100 percent penetration in medium-density residential areas (aerial plant). Although absolute costs will vary with penetration, subscriber density, and installation conditions, the relative costs for various systems should remain fairly constant, with the possible exception of the two present hub-network switched systems (Dial-a-Program and DISCADE) which run many cables in parallel (the shorter hub-network cable lengths needed in high-density areas may or may not balance the added cost of installing large multi-cable bundles in such areas).

Note that two-way digital service costs are on the basis of the additional cost of the subscriber terminal device over and above the cost of the cable plant.

Capacity Questions

Traditional single-cable CATV systems with TV-set tuning have offered a maximum of 12 program channels (VHF Channels 2 - 13), but often cannot deliver more than six or seven usable channels in the major cities because of interference caused by local VHF-TV transmitters. Three different approaches to increased capacity are being pushed by various manufacturers and/or system operators: dual-cable systems with a different group of programs on each cable, subscriber set-top converters to permit use of additional cable channels, and switched systems in which channel selection is performed remotely and only the selected channel appears on the subscriber cable (drop). Of major interest to the Commission was the comparison of these systems in such matters as channel capacity, relative cost, and advantages or disadvantages for various two-way services. The results obtained are as follows.

A program capacity of 20-26 channels is now available on a single cable with converters at a per-subscriber cost of $80, of which $30 is the converter cost. Dual cable VHF-only systems with 24-channel nominal capacity (16-20 actual) have a comparable cost ($70). With the addition of converters ($30), dual-cable capacity can be extended to 40-52 channels at a total per-subscriber cost of $100. The two present hub-network, switched systems have capacities of 20 and 36 channels, with per-subscriber costs of $113 and $186 respectively.

Single-cable converter-system technology appears to limit at about 35 channels ($50 per converter, or $100 total per subscriber). This capacity may be reached in the next few years, but extension beyond 35 channels per cable is clouded by many technical factors. Use of such improved converters in dual-cable plants would yield 70 channels ($120). Costs of doubling the two switched systems cited above to provide 70-80 channels are not as well defined, but would be about $200 and $280 respectively. The greater costs of switched systems should be balanced against other capabilities (see below).

The above cable plant costs for tree-network systems are for downstream capability only, and would be about 30 percent higher with two-way amplifiers for a two-way capability (not including terminal cost). The percentage increment in adding two-way capability to a switched cable plant is lower, but cannot yet be accurately defined.

Switched vs. Non-Switched Systems (Distribution plus some two-way)

The switched CATV systems which have appeared to date provide only for switching subscriber lines to a limited number of program distribution buses. Note that this is a much simpler switching function than that required, for example, to connect any subscriber line to any other subscriber line for a private, two-way hookup.

The conclusions are that switched program distribution systems can be roughly competitive with multi-cable or converter systems only at very high penetration levels but that they do completely avoid the present technical problems of distributing very large numbers of channels (this may not be important, however, as converter system technology improves). The Dial-a-Program system in particular appears to be less flexible from an installation standpoint unless a very high capital investment is made initially to provide 100 percent hookup capability, and has no inherent two-way advantage over non-switched systems, except for very large usage of two-way video (which does not appear probable). In fact, both switched systems now available appear to be less convenient for the more probable two-way data uses over the next 10-20 years (see next heading below). A potential, but as yet unrealized, advantage of switched systems is their ability to operate with simplified "one-channel" TV receivers.

The future of switched systems will depend on the marketplace and/or the evident or legislated need for their particular capabilities (in severe local-signal areas, point-to-point video, etc.). Costs would rise rapidly, however, in point-to-point use, because much more complicated (telephone-type) switchgear would be required. Also, the present 20 to 336-subscriber, distributed switching centers are too small for efficient point-to-point networking and larger hubs would be required, with greatly increased cable costs and perhaps individual line amplifiers.

General Comments on Two-Way Configurations

Physical configurations for obtaining upstream channels include use of sub-band channels on one cable (4 TV channels maximum), a separate upstream cable (up to 35 channels), or in switched systems, one or more channels per subscriber cable. Any of these are suitable and roughly comparable for all foreseeable subscriber video-origination requirements, particularly when it is noted that the number of simultaneous upstream TV originations is always limited by the number of available downstream channels where the signals go. On the other hand, general point-to-point video services would certainly require a hub-type switched network and a major cost escalation (see "Picturephone vs. Videophone" below).

Modern digital communication technology permits all foreseeable subscriber data requirements to be handled very economically in tree-structured systems by time-division-multiplex techniques, requiring only one "channel pair" (a downstream and an upstream channel), and a simple head-end device. For example, a one-megabit per second data loop on such a channel pair can provide about 75 bits per second continuously to each of 4000 subscriber terminals. Additional capacity, if needed, can be obtained by increasing the one-megabit rate, or by frequency multiplexing one or two more data-channel pairs. Use of a hub-type switched system actually seems to complicate the problem of providing data services since more hardware (a device per line) is required to gain sequential access to subscriber lines for polling and/or data transmission. A hierarchy of two-way services is presented below.

Hierarchical Ordering of Two-Way Cable Capabilities

The following subscriber terminal costs are over and above the cable-plant costs given above. The first three categories (data services) also require a head-end device (most probably a digital computer), but its allocated capital cost is nominal: $2 - $10 per subscriber, depending upon the data service requirements:

(1) Simple monitoring - channel monitoring; simple yes-no buttons; meter reading and alarm systems: terminal cost $50 - $100 per subscriber, plus meter upgrading costs.

(2) More general narrow-band communication and control capabilities - general-purpose keyboards; on-line channel-access control (restricted distribution; pay TV; video tape library services); audio communication (many to one, or party line); limited information retrieval: terminal cost range $125 - $250 per subscriber.

(3) General-purpose data capabilities - access to other computer systems for information retrieval, banking, shopping, etc.; electronic mail: terminal cost coat range per subscriber $250 up to $1,000 depending on desired terminal display and/or hard-copy capabilities, and total data traffic requirements.

(4) Two-way video - cost range per subscriber from "zero" for portable local origination (assuming two-way cable), to $500 per permanent home-terminal for subscriber origination capability. Total per-subscriber costs for point-to-point switched video services probably range from $2,000 - $4,000 for local connection capability only (within a head end), to $15,000 for a national network. (See "Picturephone vs. Videophone" below.)

Compatability and Standardization

So long as TV program distribution plus the most probable types of two-way data and limited local-origination are the only required cable services, and each operator provides the proper boxes to interface his system to standard TV sets or special cable receivers, all of the different types of distribution systems can co-exist (even with different channel standards), and can still be networked if desired. This compatability can be achieved at each head-end, just as it is now, by suitable channel frequency translations, etc.

Note however that the present combination of a subscriber converter and a standard TV set with tuner represents a duplication of function, and that considerable economies could be achieved by large-scale production of special cable receivers: all-channel models in the case of frequency multiplex systems, and simplified "tunerless" models in the case of switched systems. This of course raises the very pregnant question of whether the cable operator or the subscribers should own such special cable receivers, especially since a subscriber would have no guarantee that his special receiver would work on a different CATV system were he to move. Note also that the economies of very large scale can be obtained only if industry-wide standards are adopted for distribution, upstream, and data channels, and for data communication techniques. On the other hand, the technology is evolving so rapidly at present that such complete standardization within the next year or so would certainly be premature. Herein lies the horns of the dilemma.

Privacy Considerations

The privacy issue arises only when non-general-access signals exist on the cable, such as Pay-TV, or communications originated by or directed to particular subscribers. A tree-structured cable network has all its frequency multiplexed channels carried into all homes and obviously offers on opportunity (or challenge) for clandestine monitoring. A hub-structured network, on the other hand, is comparable to the telephone system in this regard — the average subscriber has no ready means of access to circuits or channels other than his own. A brief examination of this question indicates that while cable monitoring is indeed possible in frequency/time-division networks, it requires considerable technical skill, yields dubious benefits (since private signals are likely to be digital and therefore rather cryptic in nature), and can be made as difficult as desired by special encoding techniques as needed.

Telephone vs. Cable for Narrow-Band Data

A number of people have suggested that narrow-band data services would be better handled over the existing telephone lines than by adding such capability to CATV systems. The Bell System and several utility companies are currently making experiments in meter reading via telephone, and although no quoted cost figures are available, it seems clear that subscriber devices costing $100 - $150 are necessary at present, with possible eventual reduction to perhaps $50. Since a telephone call is involved in gaining access to a subscriber line, exchange switching delays limit the maximum scanning rate to about 300 subscribers per hour, even though a special exchange interface is provided for automated calling by a utility company computer. Also, a meter cannot be read when the telephone is found to be in use. To avoid interference with normal telephone service, the proposal is to read meters only during off-peak hours in telephone usage; thus the actual reading rate will be about 1,000 - 3,000 per day. The same function can be added to a cable two-way data system at a very low incremental cost ($10 - $25), with a reading rate of 4,000 or more per minute.

Picturephone vs. "Videophone"

The general need or demand for point-to-point visual communication, either on a local or national basis, has not been demonstrated, although the Bell System obviously feels that it will be a viable service eventually. It also represents a capital cost escallation over the present $500 - $600 per subscriber voice telephone plant of about 5:1 for the 1-MHz Picturephone (which can use a substantial part of existing Telco "out-of-plant" cable and local switching plant), and perhaps 20:1 for a "start-from-scratch" nationwide 6-MHz service ($12,000 per subscriber). In the latter case, about half the cost ($6,000 per subscriber) would arise in creating local hub-type, 6-MHz distribution and switching networks comparable in function to the 10,000-subscriber local exchanges on which the telephone system is based. Although this is the future role some have suggested for cable systems, these figures make it appear unreasonable to force any provisions in cable systems for future accommodation of general point-to-point video service. It is concluded that visual point-to-point services are best left to gradual addition of Picturephone facilities by the Telephone Company as the demand for such services actually arises.

CHAPTER III

COMPARISON OF HIGH-CHANNEL-COUNT SYSTEMS

The purpose of this chapter is to examine the evolving technology of high-channel-count systems, with an eye both to the question of technical factors affecting channel capacity and to the question of relative economics. The main emphasis is on downstream program distribution capability since this seems to be the overriding factor. All foreseeable two-way services can be handled with relatively few downstream and upstream channels, as discussed in Chapter IV.

The three major types of systems to be considered are: (a) multi-cable systems carrying only the standard VHF channels and using standare TV receivers, (b) augmented-channel systems using additional non-standard frequency channels and requiring either a channel converter or a special all-cable-channel receiver for each subscriber, and (c) switched systems in which channel selection is performed remotely from the subscriber's premises and either standard TV receivers or simplified "one-channel" designs can be used. Note that systems (a) and (b) can also be used in combination.

A. Background

Community antenna (CATV) systems started out as just that — carrying TV and FM-radio programs on the same frequency bands that are used in over-the-air broadcasting, and permitting subscribers to receive these programs on their standard TV and FM receivers without additional equipment. Since the practical maximum frequency that can be carried on a CATV cable (currently 300 MHz) is well below the UHF television band (470-900 MHz), a traditional single-cable system of this type can offer only the 12 VHF television channels, which occupy two frequency bands from 54 to 88, and 174 to 216 MHz. Actually, 12 channels is an upper limit which is seldom if ever obtained, particularly as CATV systems have departed from their original role of extending TV coverage into remote, marginal-reception areas and become "urbanized", i.e., moving into areas covered by strong VHF-TV stations. In such areas, direct pickup of broadcast signals in the cable and/or subscriber TV sets creates an interference with cable signals, more fully described in Appendix A, that can make the channels occupied by strong local stations unusable for cable transmission and reduce system capacity below 12 usable channels — to as little as five or six in some top-market TV areas.

At the same time, the saleability of CATV in areas where subscribers can already receive a substantial number of broadcast stations off-the-air was found to depend upon the ability to offer an expanded channel menu. Thus, simply from a marketing standpoint, the CATV industry has for a number of years been evolving ways to regain the lost channels and/or expand somewhat beyond the traditional 12-channel limit, and a few systems currently offer 15-20 channels. More recently, the concept of the "wired-nation" has emerged in which many new uses for cable channels have been proposed, leading to estimated demands ranging from 40 to as high as 60 or more distribution channels and a good deal of controversy about the technical feasibility and the economics of such numbers. In addition, various two-way video and digital data communication services are now proposed, leading to further demands on cable technology.

B. Technical Problems Relating to Channel Usage

Before getting into the relative characteristics of the three types of systems for providing more than 12 channels, it will be useful to describe one aspect of the technical environment which has influenced their evolution — the group of mutual interference problems that can occur either among cable channels in the process of their transmission to a subscriber and his selection of one of them for viewing, or between cable signals and TV or other signals propagating through the air on the same frequencies. These problems have many complex interrelationships with various system parameters — cable-system distortion factors, receiver and converter characteristics, frequency allocations for non-VHF cable channels, etc., — and an understanding of these interrelationships is important in comparing advantages and disadvantages of the three types of cable distribution systems, and in cable standardization activities. Since the details are rather voluminous, the problems are simply listed below, together with comments on their relation to the three types of systems under discussion. For complete description of these problems, please refer to Appendix A.

Several further points should be made concerning the comparison of cable transmission and over-the-air broadcasting in regard to these problems. Two of the six technical problems summarized below (on-channel pickup and cable "leakage") are peculiar to cable systems. The other four problems are almost entirely a function of the characteristics of subscriber receiving equipment (TV sets or converters) and would thus apply equally well to both cable transmission and over-the-air broadcasting, except that the FCC has effectively avoided their effects in VHF-TV broadcasting by a combination of appropriate channel frequency allocations and geographic separation of channel-usage assignments. So long as a cable system carries only the 12 standard VHF channels, it is afforded the same protection against all but one of these latter problems (adjacent-channel interference) so far as receiver characteristics go, although some of the interference effects can be generated within the cable system itself. All the problems apply in augmented-channel systems.

(1) <u>On-channel interference</u>
Interference at a subscriber's set due to direct pickup of broadcast signals from strong local VHF stations is a problem in all non-switched cable systems; the cures are the shielding of TV sets (impractical for present sets but feasible for new set designs), proper converter designs in systems using them (feasible), or a shift to a switched system using only sub-band transmission channels.

(2) <u>Intermodulation and harmonic interference</u>
These problems occur primarily in augmented-channel (converter) systems and become more serious the more the number of channels per cable is increased. They are a function of cable frequency allocations, and can arise both in the cable system and the home converters; the cures are better cable amplifiers (feasible) plus proper converter or special cable receiver design (feasible), special choice of cable channel frequencies (difficult) or a shift to VHF-only or to switched systems.

(3) Image interference

This is also primarily a problem in augmented-channel systems; the cures are special choice of cable channel frequencies (difficult) and/or proper converter design (feasible), or a shift to VHF only or switched systems.

(4) Oscillator leakage interference

This problem and its cures are roughly the same as (3) for augmented-channel systems. It has not been a problem in single- or multi-cable systems using only the 12 standard VHF channels, even though many TV sets have high leakage.

(5) Adjacent-channel interference

This is a problem that affects all non-switched systems and has been particularly troublesome in non-converter systems because many TV sets have poor adjacent-channel rejection characteristics (impractical to fix these existing sets)*; the cures are careful control of all cable single levels (already standard practice), better TV set designs for non-converter cable use (feasible but not a short-term solution), proper converter design in augmented-channel systems (feasible), or a shift to a switched system.

(6) CATV "leakage" interference with over-the-air services

The problem of signals leaking (radiating) from a cable and interfering with off-the-air reception has been confined to the past to potential interference with non-cable TV viewers because only the VHF-TV frequencies were carried on most cable systems. With the newer augmented-channel systems, there is a potential danger of interference with other non-TV services (such as air-traffic control) in case of a cable break and the FCC in the future may proscribe certain frequencies from cable usage.

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* In the Malden, Massachusetts cable system an estimated 60 percent of the service calls are for "tuner" problems, and about half of these are adjacent-channel problems, usually leading to TV-set repairs or replacement.

C. Multi-Cable Systems

The first means employed to get around the problem of "lost" channels due to direct pickup of broadcast signals was to install two or more parallel cables, each carrying different programs on the same VHF-TV channels. Drops from each cable are brought into each subscriber's home and connected to a switch which permits the subscriber to select one cable at a time for connection to his receiver. This provides a nominal 12 channels per cable, but those channels with direct pickup problems must be omitted from each cable.

1. A Typical Dual-Cable VHF System

As a typical example of this type of system, Table 3-I lists the selections available on the dual-cable system operating in Malden, Massachusetts (Malden Cablevision Co.), which include: 15 off-the-air TV station (nine VHF and five UHF), one local origination channel, two news wires (character displays), and six FM radio stations carried on TV sound channels (for reception through the TV set speaker). Note that since Channels 4, 5, and 7 cannot be carried on-channel in the Metropolitan Boston area because of direct pickup, the Malden system moves these stations to Channels 10, 11, and 12 of cable "A", substituting the FM radio programs on Channels 4, 5, and 7 of both cables. Thus to view Channel 4 (WBZ-Boston), a subscriber must set his cable selector switch to "A" and tune to Channel 10 on his TV receiver. Malden features about eight hours per day of local origination programming (town affairs, school-boy sports, etc.), and this is carried on Channel 13 of both cables.

2. Cost Data

Installation costs for a multi-cable system are of course greater than for a single-cable system, how much more depending upon whether the cables are installed sequentially (upgrading older systems) or all at one time. Double-tracking an existing cable obviously costs as much or more than the original cable since labor and material costs tend to keep rising with time, but two cables can be installed at one time at a cost about 50 percent greater than for a single cable. No exhaustive analysis of cable installation costs has been made, but figures for the Malden

TABLE 3-1

MALDEN CABLEVISION CHANNEL SELECTOR GUIDE

TO TUNE IN	SET DIAL AT	TO TUNE IN	SET DIAL AT	TO TUNE IN	SET DIAL AT
WGBH Boston	2A	WMUR Manchester	9B	WSBK Boston	8B
WBZ Boston	10A	WJAR Providence	10B	WGBX Boston	3B
WHDH Boston	11A	WENH Durham	11B	WXPO Lowell	2B
WTEV New Bedford	6B	WPRI Providence	12B	WKBG Boston	6A
WNAC Boston	12A	WSMW Worcester	9A	MALDEN	13A & B
TV NEWS SERVICES		**FM STATIONS**			
UPI News	3A	WCRB-FM	4A	WHDH-FM	5B
Stock Market	8A	WJIB-FM	4B	WBOS-FM	7A
		WPLM-FM	5A	WEEI-FM	7B

MALDEN CABLEVISION CO. Offices and Studios: 112 Pleasant St. / Malden / Mass. 02148 / (617) 324-0620

Notes: 1.) Channels 4, 5, and 7 have direct-pickup problems and are carried on cable channels 10, 11, and 12 of cable A.

2.) Channel 13 is a local origination (both cables).

system described above appear to be typical for downstream only plant.*

The Malden system was installed in 1969/70 by Jerrold Electronics Corporation under a turn-key contract for the entire system. Cable installation costs were not directly broken out, but it is believed that the average cost per mile for 86 miles of dual trunks and feeders (mostly aerial, some underground) was $5400. The system has an average density of 190 dwellings per mile, and the per-dwelling costs for trunk and feeder installation work out at $28.40, to which must be added $32.00 per subscriber drop (the actual cost in material and labor for installing a dual drop, including pro-rata share of the cable tap). Thus the total per subscriber distribution cost, assuming 100-percent penetration, is roughly $60 for VHF-only carriage (24-channels maximum) without upstream capability.

Although the Malden system can carry frequencies up to 240 MHz, it is operating VHF-only and has not yet used this super-band capability. The addition of converters as described in Paragraph 3 below would permit a substantial increase in downstream channel capacity without any changes in the cable plant. However, retrofitting for sub-band upstream transmission on both cables would add about 30 percent to the trunk and feeder costs, bringing the per-subscriber cable cost (100-percent penetration) to about $70.

3. Use of Converters in Multi-Channel Systems

As has been discussed, multi-cable systems operating directly into standard TV sets should provide 12 channels per cable, but lose the same direct-pickup channels on both cables. Thus a more typical capacity in upper-market areas is eight or nine channels per cable, down to as little as five or six in major markets such as New York City, and San Francisco. This hardly provides the channel capacity desired for "wired nation" services.

Although converter systems will be discussed more fully in the next section, it should be noted here that their current state-of-the-art is 21-25 nominal channels per cable, thus adding them to a dual-cable system immediately jumps usable capacity to the 42-50 channel region (depending on the type of converter, some of these may be lost due to

* Information on the Malden system was obtained in a visit by J. E. Ward, J. F. Reintjes, and R. G. Rausch on January 17, 1971.

direct-pickup, harmonic problems, etc.). In fact, this combination seems much more promising for obtaining such capacity than foreseeable extensions of single-cable converter technology, for reasons which will be explained in Section D below. If converter systems improve to 30 or more channels per cable in the future, combination dual-cable/converter systems can then provide 60 channels or more. The other alternative for very large capacity is a switched system (see Section E).

The addition of converters to a dual-cable system adds about $30 (current price range for 20- to 25-channel converter units) to the other per-subscriber cable-plant costs. Using the figure of $70 per subscriber for a modern two-way, dual-cable plant (from Paragraph 2 above), the total distribution cost of a dual-cable/converter system with upstream channel capability is about $100 per subscriber on a 100-percent saturation basis. This is the figure which is used as a basis for comparison with the single-cable and switched systems.

4. <u>A Modern System Plan</u>

A new system being planned for Lawrence, Massachusetts, is an interesting example of current trends, both in high-channel-count and in two-way technology.* Initially (for the first 2-3 years), the system will probably operate VHF-only with 24-channel nominal capacity (less perhaps Channels 7, 9, and 11 due to direct pickup). When suitable converters become available, it is planned that one cable will be downstream only and will provide 27 channels (2-13 and A-O) between 54 and 252 MHz. The other cable will provide 13 downstream channels (7-O) and will use a generous frequency band (from 10-108 MHz) for upstream transmission of six video channels and up to 3,500 data channels. Note that with this assymetrical arrangement, only one cable need be retrofitted for upstream transmission. The total of the above is 40 downstream channels, but indications are that it may be necessary to omit perhaps four of the mid-band channels to avoid harmonic problems, leaving an estimated 36 usable channels. Although definite cost figures are of course not yet available, the estimated per-

* Information provided by Mr. Thomas G. Polis, Director of Engineering, Greater Lawrence Community Antenna.

subscriber costs for the eventual configuration are very close to $100, as in Paragraph 3 above.

The Lawrence system is being planned with six completely independent trunks radiating from one head-end, with each trunk having feeder branches in the usual tree-network structure. One advantage of this arrangement is that it multiplies the simultaneous upstream capacity by a factor of six — to 36 upstream video channels and up to 21,000 data channels in the probable final configuration. It also offers the possibility of reusing certain channels for different local-interest programs in each of the six trunk systems. Thus this will be a sort of combination hub/tree network.

D. Augmented Channel Systems

Use of subscriber converters to solve the direct-pickup problem in cable reception dates from late 1965, when shielded VHF-VHF pre-tuners for the 12 standard VHF channels were first developed by the International Telemeter Corporation as a solution to the direct-pickup problem.* The function of these units was to perform the channel tuning in a shielded environment (instead of in the set tuner) and convert to a "quiet" channel (usually 12 or 13) to which the TV set is left tuned. Channels 12 and 13 are the best converter-output channels for a variety of reasons described in Mr. Court's paper, providing alternate output channel choices that are adjacent to insure that one or the other of them will be "quiet" in all areas. Later, converters were constructed with the capability for tuning additional non-VHF frequencies, leading to greater channel capacity per cable.

1. Characteristics of Present Augmented-Channel Converters

The cable industry has generally adopted a set of nine "mid-band" cable channels between 120 and 174 MHz (see Table A-III, page A-26), thus a converter designed to handle these mid-band channels in addition

* "Design and Use of CATV Converters," Patrick R. J. Court, Information Display, March/April, 1971.

to the standard 12 VHF channels has a maximum capacity of 21 channels. Capacity beyond 21 channels is obtained by also using the "super-band" channels which start at 216 MHz (above Channel 13) and run as high as cable bandwidth will allow. Since few presently installed cables will handle frequencies higher than 240-246 MHz, the current state of the art in tuner-converters is to include the first four or five super-band channels (216-246 MHz), yielding 25- or 26-channel capacity (these numbers were also convenient in converter design; see paragraph 2, below).

Not all converter designs on the market are of tuner type such as described above. One "tunerless" type block-converts seven mid-band channels to high-VHF band (Channels 7-13), with a switch to determine whether the TV set tunes from this group or the standard, unconverted Channels 7-13. Another type is similar in operation but block-converts seven super-band channels to Channels 7-13. Both of the above yield a 19-channel capacity. Still another unit block-converts nine mid-band channels to some part of the UHF band for tuning by the TV-set UHF tuner. This latter unit yields 21 channels, but does not provide detent-tuning for the mid-band channels (tuning is the same as for UHF broadcast stations). Since the converted channels are all adjacent, which they never are in off-the-air UHF, one might expect some difficulty in tuning, especially since the selectivity of UHF tuners is usually not as good as that of VHF tuners (actual performance of this unit in practice has not been investigated). All of the tunerless converters that convert to the high VHF band are still subject to direct-pickup problems on the VHF channels, since all tuning is done by the TV receiver.

Table 3-II lists some available converters, their conversion schemes, and total channel capacies. The tunerless converters represent a handy solution to the problem of obtaining a few more channels, but will probably disappear in the long run in favor of the tuner type (greater user convenience, more complete solution of interference problems), or new cable receiver designs which tune cable channels directly, eliminating need for a converter at all.

TABLE 3-II

CHARACTERISTICS OF AVAILABLE CONVERTERS

TUNERLESS TYPE (Block Converters):

Mfr.	Model	Conversion	Nominal channels
AEL Comm. Corp.(1)	Superband Tunerless	7 Super-Band to 7-13	19(2)
Tomco Comm., Inc.	SB-1	7 Mid-Band to 7-13	19(2)
Vikoa, Inc.	201M	9 Mid-Band to UHF	21

TUNER TYPE (Conversion to Channel 12 or 13):

Mfr.	Model	Channels			Total channels
		VHF	Mid	Super	
Craftsman Electronic Products Corp.	FV25(3)	1-13	9	4	26
Hamlin Int.	MCC-100	2-13	9	4	25
Tomco Comm., Inc.	Cable-Select II	2-13	9	4	25
TV Presentations, Inc.	Gamut 26	2-13	9	5	26

Notes: (1) Requires 258-MHz capability.

(2) Subject to direct-pickup problems on VHF channels.

(3) A push-button tuner with two banks of 13 buttons each (labeled 1-13 and A-M) and a selector switch to determine which bank is active (frequency assignment for channel 1 not given).

2. Converter Costs

Present 25-channel tuner-converter costs are quoted in the range from $30 to $50 depending on the type and manufacturer. Actually, converter technology is in a period of transition. Only a few tens of thousands of converters of all types are yet in use, and although many of these have been cleverly devised from available VHF-TV tuner components which are standard, highly tooled production items, and thus reliable and low in cost,* they do not represent an optimum solution to the interchannel interference problems in augmented-channel systems, or to further expansion of channel capacity. The industry is now moving toward new all-channel designs which can take full advantage of interference rejection possibilities (see page A-29) and the new extensions in cable bandwidth (to 300 MHz). Until large-scale production builds up over the next few years, such new designs will undoubtedly cost more than present 25-channel designs, perhaps in the $50-60 region.

Assuming that per-subscriber installation cost of a single-cable trunk and feeder system, including drops, is about $50 on a 100-percent saturation basis (based on an assumption of two-thirds of the Lawrence dual-cable system costs given in Section C above), the addition of converters to provide 25-channel capability (or more) brings the total per-subscriber cost of an augmented-channel, single-cable system to $80-$100, depending on actual converter cost.

3. Ultimate Single-Cable Capacity

There are obvious limits on the maximum number of downstream channels that can be carried on a single cable·

(a) total cable system bandwidth (largely determined by cable amplifiers,

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* For example, at least one of the 25-channel tuner-converters is constructed from two modified 13-position VHF tuner mechanisms in cascade; the first of which tunes the 12 VHF channels and the second, selected by the 13th (UHF) position, tunes 13 mid- and super-band channels. (P.R.J. Court, Ibid.)

(b) channels which may be unusable for one reason or another (interference effects),

(c) channel needs for upstream transmission.

Within the past six months, cable amplifiers giving good performance up to 300 MHz and higher have become available. One series of cable-mounted trunk and distribution amplifiers, offered by Anaconda Electronics, incorporates a postage-stamp-sized hybrid amplifier chip made by the Hewlett-Packard Company. This amplifier chip sells for only $50 and provides excellent performance from 40 to 330 MHz (±1 dB from linear slope over this range, ±0.3 dB from 40-270 MHz), with very low cross modulation and second-order intermodulation products (-89 and -80 dB, respectively).* Thus 300-MHz bandwidth is now a reality.

As discussed in Section 6 of Appendix A (pages A-24 to A-33), the question of how many usable channels can be fitted into the available downstream bandwidth between 40 MHz and 300 MHz on a single cable remains open. At face value the maximum would be (300 -42)/6 = 43 channels, but there are a number of factors which appear to militate against obtaining this exact number. These are presented in detail in Appendix A, and are simply listed here:

(a) Possible proscription of some frequencies in the 108-136 MHz region by FCC/FAA as a possible hazard to aircraft navigation/control.

(b) The present VHF Channels 5 and 6, if retained on the cable, don't fit into a contiguous-channel allocation scheme.

(c) Converters to handle such a large number of channels, and cope with all the interference effects possible in a bandwidth of almost three octaves, remain to be demonstrated. Some particular channels may present unsolvable problems and have to be left idle.

It is certain that converter technology will progress beyond the present plateau of 25-26 channels, and may reach 30 - 35

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* HP Specifications "Exhibit C" dated March 15, 1971 for H01-35602A and H02-35602A amplifiers.

channels in the near future. How close one can come to completely filling the available bandwidth with usable channels remains to be seen.

E. Switched Systems

1. Introduction

The previous sections have discussed progress and prospects in the extension of traditional CATV technology, which amounts to broadcasting on a cable network rather than through the air. At least two CATV equipment companies have recently decided that the many complex interference problems encountered in the frequency multiplexing of large numbers of TV channels on an imperfect medium (cable) and the selection among them by subscriber-end "de-multiplexers" (converters and/or TV-set tuners) are better solved, at least in the urban multi-VHF-station environment, by adoption of a completely different approach — remote channel selection in "centralized" switching equipment and transmission of only one (or a few) channels per cable at sub-VHF-band frequencies (less than 50 MHz) selected for minimum interference problems. This of course requires that the subscriber "drops" must be extended to a common point where the selection switching is performed, instead of simply being tapped into the nearest point on a multi-channel, frequency-division-multiplex trunk/feeder system that carries the same signal menu past all subscribers.

The radiating structure of the drops in switched systems characterizes them as "hub networks", as opposed to the conventional CATV "tree network". Since the telephone system as a point-to-point communication service is also a hub network, considerable speculation has developed about this similarity and the possibility of enlarging and/or merging functions, up to and including two-way, point-to-point "videophone" services on the same broadband subscriber cables used for CATV distribution. The intent of this section is not to address this question per se, but to compare the emerging switched-CATV systems with the conventional non-switched systems as a means of distributing large numbers of channels. Two-way features and possibilities are also noted. Point-to-point switched video is discussed in Chapter IV.

The two switched systems to be discussed are the Dial-a-Program™ system offered by Rediffusion International, Ltd., and the DISCADE™ (DIScrete Cable Area Distribution Equipment) offered by Ameco, Inc., both of which started trial operations in mid-1970 — Dial-a-Program in Dennis Port, Massachusetts, and DISCADE in Daly City, California (now being expanded into a full-scale 20-channel installation by the system operator).* Because of the important ramifications of this new CATV concept, these systems were thoroughly investigated and reported upon in separate interim memoranda submitted during the course of the study. Revised versions, based on respective review and comment by Rediffusion and Ameco, are included here as Appendices B and C and should be referred to for details of system characteristics and cost analysis. Important summary information is presented below.

2. The Rediffusion Dial-a-Program System

As described in Appendix B, the Rediffusion approach is to perform channel selection remotely in switching units capable of handling 336 or more subscribers, and transmit only the one selected channel to the subscriber on a private "drop" wire. A novel feature of the system is the use of a very low frequency distribution channel (3.19 to 9.19 MHz) that can be sent over low-cost twisted wires (instead of coaxial cable) for distances of up to 2,000 feet without amplification. The wires are of the same gauge as the twisted pairs used in telephone systems, but are constructed in a special configuration called a Qwist™ (four wires twisted together). Figure 3-1 shows two forms of this cable: a single Qwist used for the final drop into a subscriber's premises, and a "6-way" feeder Qwist (six Qwists in one sheath) used to extend groups of subscriber drops to the switching exchange. One wire-pair in each Qwist was designed for the program channel, the other wire-pair for switching control. (Rediffusion is currently experimenting with switching control on the program pair, leaving the other pair completely free for other uses.)

The present switching exchange design utilizes rotary, mechanical selectors and permits remote selection of any one of 36 channels. This could be extended to 72 or 108 channels (or more) either by paralleling exchanges of the present design, or by redesigning with larger selectors; in either case without any alteration of the distribution cable network or

*Announcement was made in October, 1971, that DISCADE has also been selected for a major installation in Salt Lake City.

Fig. 3-1 Qwist^{TM} Distribution Cable (Rediffusion International, Ltd.)

the subscriber equipment. Thus of all the systems examined, the Dial-a-Program system seems to easily win the channel "numbers game".

In hub networks, total cable-footage required rises much more rapidly as a function of area served than in tree networks, thus there is a dual impetus to keep per-foot cable cost low (as Rediffusion has) and to disperse switching centers to serve relatively small areas. With 336-subscriber exchanges and a 2,000-foot maximum "reach" of subscriber drops, exchange density would be in the range from four to ten per square mile, depending on living density and penetration. In analyzing the cost of a Dial-a-Program installation, the decision was made that the best comparison with non-switched systems would be obtained by considering all costs associated with a single exchange installed in a medium-density single-dwelling area (50 by 100 foot lots) on a 100-percent penetration basis. The analysis, presented in detail in Appendix B, includes the exchange equipment plus land and housing for it, the distribution cable network, subscriber equipment, connecting inter-exchange trunk, and a 40-percent allowance for multiple subscribers. (Note that those subscribers with more than one TV set which they wish to use independently require a separate drop and exchange selector.) Head-end costs were excluded, since these are roughly the same for all systems.

The resulting distribution cost for a 36-channel Dial-a-Program system is $186 per subscriber. This is considerably higher than the figures for dual-cable and/or converter systems with comparable channel count, and must be balanced against the additional features of the Dial-a-Program system. The channel extension possibilities have already been mentioned. Another is that there is a ready-made, private upstream video channel from each subscriber to the exchange, using 9-15 MHz on the same Qwist pair used for the downstream channel (requires additional equipment at both ends). This permits many simultaneous originations from all points in the system, and could form the basis for a point-to-point, two-way videophone service if additional switching facilities were provided.

Although the Rediffusion subscriber-selector unit ($31) converts the cable channel to Channel 12 or 13 for reception on standard TV sets, it could as easily operate with simplified (tunerless) TV sets by converting to the IF frequency. In fact, Rediffusion estimates 30-percent cost savings for special receivers incorporating their dial-selector unit in place of the usual UHF/VHF tuner. Finally, the complete freedom from all multiplexed-channel interference effects should be considered.

3. The Ameco DISCADE System

On close inspection, the DISCADE system described in Appendix C is found to be a cross-blending of the traditional tree-structured VHF cable system and a switched, sub-band system as described above. The DISCADE solid-state switching units (Area Distribution Centers) are in smaller sizes (8, 16, or 24 subscribers) and are spliced into aerial or underground cables in the same manner as the usual cable line amplifiers. The network itself is tree-structured, with trunks and feeders (called sub-trunks by Ameco) laid out in the usual pattern. The important difference is that these all have ten coaxial cables running in parallel, each carrying two or four channels frequency multiplexed in a band of frequencies from 5-50 MHz. This provides either 20 or 40 channels total. Because of this low range of channel frequencies, smaller coaxial cables can be used than in VHF or augmented-channel systems, thus cost per mile for the network is not much greater than for a modern dual-cable system (Ameco estimates $11,000 per mile for trunk, $7,500 per mile for sub-trunk, including switch housings, and that the typical ratio of sub-trunk to trunk footage is 10:1).

Each subscriber has a $15 selector-converter unit and single coaxial drop cable (up to 2,000 feet) to the nearest Area Distribution Center (ADC). The largest element of cost is that one 10-pole solid-state switching module must be plugged in to the ADC for each connected subscriber, and these cost $60 each. As in the Rediffusion Dial-a-Program system, multiple TV sets in a single dwelling require separate selectors, drops, and switch modules if they are to be used independently. Details of the hybrid space/frequency selection switching are presented in Appendix C.

The cost analysis of the DISCADE system was carried out under exactly the same assumptions as for the Dial-a-Program system, and resulted in a figure of $113 per subscriber, very close to the figures for dual-cable and augmented-channel systems of comparable channel count. For comparison with the Rediffusion system, the present implementation does not include any upstream channels, nor has a definite plan been stated by Ameco. Some ideas as to how upstream capabilities could be implemented are described in Appendix C, but there is no way to estimate the costs involved. The network and switching arrangement does not seem to lend itself as easily as the Rediffusion system to any future requirements for point-to-point two-way services. Also, increase in channels beyond 40 would require one additional trunk and sub-trunk cable throughout the system per four channels added, plus either design of new ADC's and larger switching modules, or paralleling of the present units in some way.

On the plus side, DISCADE shares with Dial-a-Program almost complete immunity to the interference effects in the usual multiplexed-channel VHF systems, and the ability to use simplified (tunerless) TV receivers. One such application of DISCADE at Disneyworld, Florida, is described in Appendix C. Also, the DISCADE system has the advantage that all its equipment is cable-mounted, requiring no real estate to install large switching equipment. Further, it seems more flexible in regard to growth from low to high penetration, since trunks and sub-trunks could be installed throughout an area at about the same per-mile "wire-up" costs as present dual-cable VHF systems (if Ameco's figures are correct), with ADC's being installed only where and when needed to meet actual subscriber hook-up requirements. The Rediffusion exchanges, on the other hand, would have to all (or mostly all) be installed at the outset because they are part of the trunk system, and require ground real estate which would need considerable advance planning and preparation for acquisition, particularly in already settled communities.

The two systems are basically alike in concept, however, and their present technology can and probably will metamorphose as needed to be competitive and to meet any actual or expected demands for two-way data and/or video communications services.

CHAPTER IV

TWO-WAY CONSIDERATIONS AND SYSTEMS

A. Introduction

This chapter discusses the emerging technology of two-way communication on CATV cables and prospects for the future. Except for a few experimental installations and trials during the past year or so, existing cable plants are only equipped with one-way downstream amplifiers in the trunk lines for the normal TV distribution band from 54 to 216+ MHz. By use of suitable frequency splitters at each downstream amplifier location, it has been found possible to add amplifiers to selectively transmit frequencies below this band (i.e., from roughly 5-40 MHz) in the upstream direction.* A number of CATV equipment manufacturers are now beginning to offer such devices, either for new systems or the upgrading of older ones, with the exact frequency range provided varying with the manufacturer.

The availability of say 30 MHz of upstream bandwidth permits up to five 6-MHz upstream channels, some of which can be used for remote TV originations from any point in the system and some for a variety of digital data purposes. Whether five upstream channels is sufficient depends upon what services one wants to provide. To go beyond this, some proposals are to install a separate cable with full upstream bandwidth, use a greater share of one or both cables in dual-cable installations, or as in the Rediffusion Dial-a-Vision switched system, provide a separate upstream channel from each subscriber to his program exchange. Whatever the needs, it is clear that substantial upstream cable capacity can be provided within the state of the art and within a factor of two (or less) of the cost of downstream-only configurations.

*See for example: "The Real World of Technological Evolution in Broadband Communications", H. J. Schlafly, report prepared for the Sloan Commission on Cable Communications, September, 1970.

B. Upstream Television Channels

The first paragraph below discusses the current trends in the industry, i.e., what is now possible or will be shortly. The second paragraph treats the question of expanding CATV systems to include full two-way, private video transmission on a subscriber-to-subscriber basis and concludes that this would be very expensive and would not fit within tree-structured CATV systems.

1. Present Capabilities

The most obvious use for an upstream TV capability is to permit cablecast originations from any point in the system, transmitting the camera signal back to the head-end or the cable-casting studio for taping and/or live retransmission on a regular downstream channel for general viewing. Needs for such service can probably be satisfied by a few upstream channels on an occasional-usage basis.

The next level of service is to provide certain restricted-access, subscriber-origination video transmission services not connected with general CATV program distribution, such as the interconnection of TV-visual services between schools, municipal or police visual nets, etc. This would add to the needs for upstream channels, both in the number of simultaneous channels required, and in average usage. Note also that in order to provide such point-to-point or "one-to-few" services passing through the head-end, a controlled-access downstream channel is required for each upstream channel so used. An interesting example of this class of service is a community conference hookup permitting a controlled group of subscribers (the conferees) to view and participate verbally with their chairman (another subscriber who has a camera and means for controlling viewing access). Such a system is being developed by Vicom Industries, Inc., Dexter, Michigan, and as described in Section C below, they plan to use three upstream and three downstream TV channels (plus additional audio and data channels) to provide for three such conference hookups simultaneously.

2. <u>The Cloudy Future</u>

Beyond the above types of video services that can now or very shortly be offered, there has been speculation about personal point-to-point video services, such as remote medical diagnosis, general "video-phone" service, etc. These of course imply permanent installation of cameras and cable modulators at subscriber locations, which would represent a major cost escalation — by at least $500 per subscriber even when such devices are in large-scale production, and perhaps more. More important from the viewpoint of the cable plant, the number of independent two-way channels needed would be far in excess of the foreseeable extensions of present cable technology, except perhaps for the Rediffusion Dial-a-Program system. Note however that in the Rediffusion system as presently implemented, the individual two-way subscriber lines have a "reach" of only 2,000 feet and the largest hub is 336 lines, which is a rather small base for a generalized point-to-point switching network (the balance of interexchange lines to subscriber lines would be very poor). Whether or not the subscriber lines were extended (with two-way amplifiers and/or a change to coaxial cable) to permit larger hubs, total switching gear at least comparable in complexity to the usual 10,000-subscriber telephone exchange would be needed within a typical head-end, since the switching requirements would be the same.

Large-scale point-to-point switching apparatus for 6-MHz channels is probably feasible, particularly if the signals can be handled at baseband-video or at very low carrier frequencies such as used by Rediffusion and Ameco. The Bell System already can switch 1-MHz Picturephone signal on modified No. 5 crossbar and ESS equipment, and solid-state video crossbar switches (116 by 211 lines) have been constructed for NASA. Large-scale broadband switchgear would have to be developed, however, and would certainly be more costly than present telephone switchgear. Also, interconnections between exchanges would require broadband trunk circuits (in the telephone system sense) which would become extremely costly as the size of the interconnected system expands (one 6-MHz channel occupies the same bandwidth as 1,000 voice-grade telephone channels). Minimum investment costs for the most modern long-haul terrestrial telecommunications systems are \$1,750 per channel-mile for 6-MHz television channels (TD-2 Microwave Relay).* Present proposals for a domestic satelite (with a backup satelite) are based on providing eight 6-MHz TV channels (or 10,560 voice channels) at an investment cost of \$47 million. Annual lease of a two-way TV circuit (two channels) is expected to be \$1.8 million, or \$5,000 per day (from FCC filings by GT and E/Hughes, 1970).

In this connection, one study by Complan Associates, Inc.** has estimated the added capital cost of a complete nationwide 1-MHz Picturephone service serving 100 million subscribers to be \$3,000 per subscriber, about five times greater than the investment in the existing voice-grade telephone system, and that a 6-MHz service on the same basis would cost about 1.2 trillion dollars (\$12,000 per subscriber). In both estimates, "out-of-plant" and local exchange costs (subscriber lines and terminals, and first-level switching) account for one-third to one-half of the total, thus two-way 6-MHz "videophone" service just within a typical CATV head-end (10,000 subscribers) would cost at least \$4,000 per subscriber, perhaps 20 times more than the most probable types of CATV configurations over the next few years.

It should be noted that no analysis comparable to that of the Complan study has been made for generalized point-to-point services during the course of this study. Whether the estimates presented above are correct or not, however, it is clear that the cost multiplier for expansion of CATV systems to include generalized point-to-point switched "videophone" service is quite large and that a hub-type network would be required.

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* "Investment cost of Terrestrial Long-Haul Telecommunications Facilities", R.D. Swensen, IEEE Transactions on Aerospace and Electronics Systems, Vol. AES-7, No. 1, January, 1971, pp. 115-121.

** President's Task Force on Communications Policy, Staff Paper I, Part 2, Appendix I, Clearinghouse No. PB 184413, June, 1969.

C. Digital Channels for Control, Monitoring, and Data Services

There is a wide range of services one can imagine for digital communication via the cable plant. Some of the simpler ones include providing the head-end with information concerning the operation of the cable plant via equipment sensors, or the monitoring of the tuner of each subscriber to gather viewing statistics. Several test installations of this sort are now in progress, and new equipments for these purposes are now coming on the market. Moreover, if current computer communications techniques are employed, it is possible to provide (in order of ascending cost) such services as push-button opinion samples or voting, meter reading, data entry and retrieval from local or remote data banks, electronic mail, and so forth. In the remainder of this section an attempt will be made to examine the technical features and costs of successively more complex systems.

Digital communication on a tree-structured CATV cable is based on the concept of a shared party line, with subscriber stations speaking only when spoken to, i. upon receipt of an addressed message. Herein lies one of the interesting problems in devising high-data-rate channels — how to avoid a high overhead in lost channel time due to the variation in round-trip transmission time as a function of subscriber distance, at the same time preventing any possibility of response overlaps. This issue is discussed in the first paragraph below, which includes a proposal for a compensating delay scheme. Subsequent paragraphs discuss the characteristics of three new two-way digital systems, in order of increasing sophistication. The final paragraph discusses the privacy issue.

1. An Approach to Upstream Communication*

This note indicates some factors which influence upstream digital data rates for a tree-configured cable communication system. It is shown that data rates close to absolute maximums can be achieved for two different types of systems with very modest equipment. In order to determine

* An unpublished memorandum prepared by Professor James K. Roberge, March, 1971.

data rates it is necessary to assume certain parameters for the system under study. These assumptions are not restrictive since rates which depend on them can be readily scaled to determine the performance of different size systems.

The system under study is assumed to have a single one-megabit-per-second digital channel devoted to upstream communication, as well as a downstream channel used to poll the subscriber stations. The average downstream data rate required for polling is low, so this channel can also be used for communication with subscriber stations or for other unrelated functions. The system serves 10,000 subscribers, and the one-way cable distance from the head end to the most remote station is 10 miles.

The simplest system is one where all subscribers are polled sequentially, with a fixed time alotted for reply. This approach limits the maximum upstream data rate of any single subscriber to $10^6 \div 10^4 =$ 100 bits per second. This rate is an asymptotic limit which can be closely approached only if some method is included to minimize effects of cable delays.

If no additional delays are introduced at subscriber stations, messages provided in response to polling will be delayed by the round-trip cable transit time between the head end and the subscriber station. This delay depends on the velocity of signal propogation in the cable, and has a maximum value of 150 μs for a 10-mile system using cable with average characteristics. Assuming no compensating techniques are used, this maximum delay represents a dead time overhead which must be included as part of every response interval. The total length of a response interval is dependent on the length of the message transmitted by the subscriber stations each time they are addressed. If a 150-bit message is transmitted by each station, the dead-time overhead reduces the effective average bit rate to 50 bits per second. A message length of 1,500 bits would be required to increase the average bit rate to 90 percent of its asymptotic value, or 90 bits per second. (The above assumes a storage capacity in the terminal for the required message length.)

System complexity can be reduced if some form of compensation is used which reduces the local memory required to achieve a given fraction of the asymptotic bit rate limit. One approach is to adjust the actual polling interval as a function of the distance of the station being polled. The required timing information could be stored in the computer which is presumably located at the head end. This method expands the memory requirements at the head end and also complicates any schemes which time share polling with other functions on a single downstream cable.

A second approach would be to introduce in each subscriber station a compensating delay between the time it detects a pole and the time it starts to respond. Stations located near the head end of the cable would be adjusted for a 150 µs delay, while the most remote stations would have no delay. If delays were correctly chosen, responses would always be detected at the head end 150 µs following polling, and the maximum data rate could be achieved with a constant-frequency, overlapped polling technique. While this method can conceptually be used with no local storage, the minimum practical storage is determined by inaccuracies in the compensating delay. If it is assumed that the delay time can be controlled to within 10 µs (certainly realistic for simple one-shot type circuits), the actual bit rate becomes 99% of the asymptotic value with 100 bits of local storage.*

Once the dead-time overhead has been minimized, further increases in capacity are possible only by limiting the number of users who may simultaneously use the system to some fraction of the total number of subscribers. Assume a system which limits the number of simultaneous users to 1,000. Such a system might be organized as follows. A basic time period which allows time for 1,000 equal-length responses is selected. (This time is determined by allowable dead-time overhead and delay time uncertainties as described earlier.) If the system is free

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* Some people have proposed a cable configuration which would achieve much this same effect. This would be to send responses downstream to the farthest end of the cable where they would be returned to the head-end on a separate upstream cable. Signal splitting at the feeder/trunk nodes would be quite complicated, however.

of all users, all subscribers are sequentially polled to determine if they wish to get on the system. A complete polling sequence requires 10 basic time periods to poll all 10,000 stations. When station A indicates that it wants regular service, it will be assigned the first response time of each interval, thus assuring uniformly staggered response intervals and an asymptotic bit rate of 1,000 bits per second to station A. Other stations are polled sequentially during the remaining 999 segments of each basic interval, so that slightly more than 10 intervals are required to poll all out-of-service stations. As more stations join the system, they are assigned definite response intervals, and the average rate of polling out-of-service stations decreases. Thus the frequency at which an out-of-service station is polled indicates the degree of loading on the system. When the system is accommodating 1,000 users, it indicates its busy status by never polling out-of-service stations. Stations which cease responding will be returned to out-of-service status to prevent their blocking the system.

Many alternative strategies exist. For example, active stations could receive either more frequent or longer intervals for data transmission when the system is lightly loaded. The disadvantage is that a more sophisticated subscriber station is required to take advantage of the variable data rate available to it. With the system approach described above, users are assured a known data rate, with uniformly timed intervals for data transmission, whenever they gain access to the upstream cable. If higher upstream data rates are required at any location, multiple stations can be employed.

2. Vikoa Incorporated

The system developed by Vikoa appears to have been designed specifically for monitoring the channel being viewed by the subscriber. The system is very slow in comparison to others, requiring 116 miliseconds to poll a single subscriber-response unit for a 5-bit binary number providing for up to 32 different responses. The basic system incorporates a two-level addressing scheme, with 30 groups of 30 subscribers each, or 900 subscribers per outbound command channel. More subscribers can be serviced by frequency multiplexing additional independent command channels. The polling process takes place as follows: the command channel transmits two five-bit characters, using five-frequency tone modulation, to identify the sub-group and subscriber; the next 5 bit times (83.5 ms) are allocated to the response data from the transponder within the subscriber home. This response is transmitted serially using frequency shift keying (FSK) at 60 bits per second.

This system can also be expanded to include alarm monitoring systems and error detection monitors for the cable plant itself. It would be possible to add several bits to the transponder response sequence and thereby interrogate a small set of push buttons on the subscriber unit. At the six-per-second poll rate, however, 1.9 minutes would be required to read the response from all 900 subscribers. This appears to be the limit of the capabilities of the system, and expansion to higher data rates is not possible within this framework. The expected cost of the subscriber unit is $30.00.

3. Electronic Industrial Engineering, Inc.

The EIE system has been designed for limited two-way digital communication with as many as 30,000 subscribers, and differs from the other systems described in this section in that the control unit and digital encoder are located at the cable tap — not in the subscriber's home.* A dual drop is used: one for video program distribution and one for digital signals. Since the unit is designed for use with either converter systems or dual-cable VHF-only plants, it does not include a converter. Currently configured systems include a four-button opinion polling device and a set monitor, but this system can be expanded to include meter reading, cable telemetry, alarm systems and general-purpose keyboards.

The system is designed to use a downstream control channel in the FM band (88-108 MHz) and a return channel at 2 MHz. Each poll consists of a 15-bit subscriber address and a 15-bit command. The response is 128 bits of data which includes the 15-bit subscriber address as an identification. All data transfers are performed on a

* EIE feels that this setup provides for easier servicing and can maintain return-channel security.

time-division-multiplex basis which allows 30,000 subscribers to be polled in 22 seconds. Current costs for the subscriber unit are $1,000 per subscriber, but projected costs range from $150 to $200 per subscriber when mass produced.

4. Vicom Industries, Inc.

The most extensive two-way system concept of those discussed here is that being tested and demonstrated by Vicom.* The Vicom system is intended to be a complete interactive digital system and has provisions for channel-usage control, data transmission and on-line interaction with the viewing audience (including both keyboard and audio response); all controlled by a computer located at the head-end. Two channels are required to operate the system: the outbound command and control channel operates at a one-megabit rate and transmits 20-bit words at 40,000 words per second to the subscriber terminals. These words are interpreted as either data for a terminal, commands to a terminal, or the polling of a terminal for a response. In any case, the terminal is expected to respond to every poll with its address and a single data character, and return response is at the same one-megabit rate.

The home terminal provides (1) basic keyboard entry via 12 momentary contact keys, (2) a microphone for audio responses, (3) a later model will have storage for up to 16 alphanumeric characters to be displayed on the TV-set screen, and (4) a 25-channel converter that may be enabled/disabled under head-end control. Provision is also made for attaching a variety of peripheral devices to the terminal as demanded by the application. These peripherals consist of:

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* Details of the Vicom system were obtained in a visit to their plant in Dexter, Michigan, by J.E. Ward and R.G. Rausch on February 25, 1971. We were most cordially welcomed by Mr. Harold W. Katz, President, and all features to be described were demonstrated to us by means of a five-subscriber hookup within the plant. The computer in use was a DEC PDP-8 (about $10,000 plus a special communications interface), but a system using a slightly larger computer was under construction. They estimated computer capital cost at about $5 to $15 per subscriber, depending on the type of data service rendered, based on 4,000 subscribers. Present cost of the home terminal with capabilities as described here is $265, with a projected cost in large-scale production of about $135.

Since this was written, Telecable, Inc. (a Norfolk, Va.-based MSO) has announced a test of the Vicom terminal in Overland Park, Kansas, with two-way cable facilities produced by EIE. The tests involve home instruction for disabled children, and home shopping demonstrations in cooperation with Sears Roebuck.

(1) Video cameras
(2) Full-screen alphanumeric generators
(3) Hard-copy printers
(4) Full keyboard typewriters.

A key feature of the Vicom system is the head-end control of who may view any channel. This is accomplished by automatically disabling the converter whenever its channel selector is moved and sending the number of the newly selected channel to the head-end as a response to the next poll. The converter can only be re-enabled by receipt of an enable command from the head-end computer. This is designed for ready implementation of pay-TV and also for controlled-group conferences, as described in the preceding section. The system permits transfer of access-control over a given channel to any subscriber, for instance, the chairman of a conference connection. This control includes the enabling and disabling of the microphones of other subscribers on an individual basis. Thus a person may indicate his desire to speak by pushing a button, but can do so only after the proper enable command is transmitted to his terminal by whoever has control. This control over audio signals is important because the audio channels are handled on a party-line basis.

In order to control the data flow for the programming associated with this equipment, a pair of channels is allocated for the command and response functions. The downstream channel is presently located in the 108-114 MHz band, and the upstream channel is 6-10 MHz. All of the data transmission is on a time-division-multiplex (TDM) basis, and a word consists of 20 one-microsecond bits. Each terminal is addressed at a rate which depends upon the particular application requested by the subscriber, and is controlled by the head-end computer. The rate varies from the order of once per second to five per second for routine polling, and for full-screen display modes, up to 5,000 words per second can be transmitted to a single subscriber (this can be extended to 30,000 words per second if required).

In general, the Vicom system seems to provide a wide range of subscriber interaction and to have a great potential for data transmission both to and from the subscriber. Currently the system is designed for single-cable use and provides 25 forward video channels, 3 reverse video channels, 3 reverse audio channels, and 1 forward and 1 reverse digital channel. This implies that no more than three party line conversations can take place at a time. Vicom stated however that their system could be used with any cable configuration, including the Rediffusion switched system, and channel mix is flexible. The number of party-line interactions is not limited to three by the terminal design.

For the purpose of illustrating the potentials for such a system as that configured by Vicom, consider the following system: 4,000 subscribers and a cable plant which yields a worst-case distance from head-end to subscribers of 5 miles, or a round-trip cable delay of 75 µs. Command and data could be formatted in 20-bit characters as follows:*

	1 Bit	12 Bits	7 Bits	
Command (1)	1	Address	Command	
Data (2)	0	Modifier	data	data
		3-bits	8-bits	8-bits

Format (1) above can be used to transmit commands to the subscriber terminal such as: enable channel, set inbound channel A, enable voice, prepare to transmit/receive data, etc. Format (2) above can be used to transmit data to a previously addressed terminal. Assuming that asynchronous communications conventions would be used the total number of bits transmitted per word would be 23; 1 start bit, 20 data bits, and 2 stop bits. With asynchronous conventions, the time between characters is only restricted to being not less than 2 bit times but may be longer to account for cable delays or longer terminal responses.

For the remaining computations we will assume that the home terminals have a built-in delay mechanism such that cable delays may be ignored (except for a 10 µs accuracy limit) and polls sent continuously.** Then the transmission of a single poll command would require 23 bit times plus 10 µs, or a total of 33 µs for a 1-megabit transmission speed.

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* Vicom considers the details of its message coding proprietary; this is our estimate of how it might be organized.

** As described in paragraph 1 above.

The resultant poll rate is 30,000 polls per second which could be used to provide a 7.5 character per second data channel to all 4,000 subscribers. If we assume that the background user need not be polled more often than once per second if his set is on and once every five seconds if his set is off, the peak minimum poll rate would be 4,000 subscribers/second with an excess capability of 26,000 polls per second which could be allocated to various subscribers on a demand basis for data entry and retrieval, yielding an ultimate capacity of 50,000 characters per second.

If on the other hand, we assume that cable delays must be allowed for (i.e., that the computer must always wait for a response before sending a new poll), the time per poll must be that for the most, distant subscriber: $23 + 75 \approx 100\ \mu s$. This yields an effective poll rate of 10,000 polls per second; subtracting 4,000 polls as the minimum rate we get an excess capability of 6,000 polls per second to be allocated on demand. Ordering of the poll sequence on the basis of the distance of each subscriber can improve this figure somewhat, and is what Vicom plans to do, but the desirability of a system of eliminating the problems of cable delays should be obvious.

5. <u>Privacy Issues on the Cable</u>*

Privacy of communications is a subject that has recently been receiving more attention. Most techniques for digital communications on a cable involve a greater potential for eavesdropping than exists with the telephone system. This is because most CATV systems involve piping all communications going over the cable into the premises of each subscriber where his terminal picks off only those messages intended for him. This means that any subscriber can listen into any other messages by adapting his terminal or replacing it with another one designed for eavesdropping. In a cable digital system such as those described above, someone who wants to can listen to all the messages on the system with only one device, particularly if there is only one digital channel that is time-division multiplexed (TDM) among all the users.

* Prepared by Paul J. Fox, EE graduate student.

It is not enough however, to say that a cable digital system provides less security than the telephone system. The telephone system does not provide complete security. Wiretapping is not unduly complicated for someone who really wants to. The relevant question is whether there are a substantial number of people who would undertake the effort needed to eavesdrop on a cable system but not a telephone system, for obtaining useful information from listening to a TDM digital channel is non-trivial. One has to decode the addressing or timing procedure and other signal protocols. While not overly difficult it does require a serious commitment of time and effort to understand what one is intercepting. There is however, one fundamental difference between the telephone system and a cable digital system. Any eavesdropping on the telephone system must involve connection somewhere of a physical device which can be detected and found if one is willing to devote enough time and effort to the project. Any subscriber to a cable system does not need a special physical device or connection to listen to his neighbors messages — only modification of the legally connected device he already has — and even if a special connection were used, it would be much more difficult to detect its presence electrically because of the party-line configuration. For those cases in which security of a cable system is important, the digital nature of the messages makes it easy to add cryptographic devices to the system, in fact, this has already been provided for in the Vicom system.

The above remarks of course pertain to a tree-structured cable network. If a hub-type network is employed with space switching, privacy problems are little different than in the telephone system.

APPENDIX A

INTER-CHANNEL INTERFERENCE AND THE CABLE-FREQUENCY ALLOCATION PROBLEM

1. Introduction

The CATV industry, in its effort to break out of the traditional pattern of 12 channels (or less) per cable, has only recently begun to make use of channel frequencies that are different from the standard VHF-TV channels for which all TV receivers are designed. The initial move in this direction was to take advantage of 66 MHz of unused bandwidth that was already being carried in all cable systems — that between the upper edge of the FM band (108 MHz) and the lower edge of Channel 7 (174 MHz). By general industry acceptance (but not specific standardization), a "mid-band" has been defined from 120 - 174 MHz, divided into 9 channels designated A through H (the 108 - 120 MHz region is apparently avoided because of possible interference effects of cable leakage on aeronautical radio and navigation services, although these services actually extend to 136 MHz). Use of these mid-band frequencies, which requires a special channel converter device at each subscriber TV location, permits 21-channel capacity (12 VHF plus 9 mid-band), and a few cable systems now offer such service.*

Once started on this tack, it was natural to define a "super-band" starting at 216-MHz (the upper edge of Channel 13), with the upper limit of this essentially open-ended. Many of the newer cable systems are engineered to carry frequencies up to 240 MHz, permitting four super-band channels (I through L) and 25-channel total capacity (with appropriate converters). With 300-MHz cable technology now

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*A variety of conversion schemes have been developed for mid-band. Some are simple block-converters which transpose the mid-band to UHF or to high-band VHF for selection by the respective tuners of the TV receiver. Others are complete 21-channel tuners (more if super-band is included) which perform the channel selection and convert to an unused VHF channel, to which the TV receiver is left tuned. (See Section D, Chapter III).

becoming available, the super-band can be extended to provide nine additional channels M through U, or a total of 35 channels per cable (with mid-band as presently defined). Similarly, a "sub-band" has been defined in the region below 50 MHz, with the general consensus that this band will be used for upstream channels (signals moving from the subscribers toward the head end). Some proposals are for four upstream channels between 6 and 30 MHz, but no general agreement has been reached as yet on channel assignments or usage, and the first upstream experiments are barely under way.

Unfortunately, adding these extra channels on a cable can and does raise problems of inter-channel interference that do not arise with use of only VHF Channels 2 through 13 (either broadcast or on the cable), largely because the frequencies for these VHF channels were chosen by the FCC partly on the basis of avoiding such problems. The intent of this discourse is not to say that these inter-channel interference problems are unsurmountable in augmented-channel cable systems, but to clearly define them, explain how they come about, and point out the precautions that must be taken in the design of subscriber equipment (converters or special cable receivers) and in the final agreement on cable-channel frequencies.

Since most of the interference questions revolve around the basic U. S. 6-MHz television channel standard and the carrier frequencies assigned within it, this subject is taken up first in Section 2, followed by a brief background in Section 3 on the historical development of the VHF allocations. The inter-channel interference effects are then discussed in detail in Section 4, including examples of their impact on the rules adopted by the FCC for geographic separations of channel assignments in VHF and UHF television broadcasting.

Cable systems are also subject to two other interference problems not found in TV broadcasting: the leakage of strong, local TV station signals into the cable or receivers to interfere with cable signals (a real problem in present cable systems), and the leakage (radiation) of signals out of the cable to interfere with other radio frequency services (a potential problem in the use of non-VHF-TV channels). These problems are discussed in Section 5.

Finally, Section 6 discusses the intensive industry/government debate just getting under way on frequency allocations for broadband cable systems.

2. The 6-MHz Television Channel

The origins of 6-MHz channel bandwidth standard for U. S. TV are rather interesting. In the early 1930's, the first experimental television systems used the same double-sideband amplitude modulation technique that is still used in AM radio. The highest picture frequency component then transmitted was 2.5 MHz, and the picture signal thus required a 5-MHz channel, with the picture carrier in the center. To provide space for the sound signal, an extra 1-MHz was tacked onto the high side of this picture channel to create a total 6-MHz channel, with the FM sound carrier 0.25 MHz below the upper band edge (as it is now).

In the late 1930's, vestigal-sideband modulation techniques were perfected which permitted an increase in picture component frequencies (and thus in picture resolution) without increasing the 6-MHz channel bandwidth. With the change to vestigal-sideband modulation, all but 0.75 MHz of the lower picture sideband was eliminated and it became possible to move the picture carrier down to 1.25 MHz above the lower band edge (as it is now) and use modulation frequencies up to 4 MHz in the upper sideband. This of course obsoleted all existing receivers, but only a handful had yet been produced (television broadcasting was still largely experimental). Although these revised standards in 1939-40 were for monochrome transmission at only 441 lines per frame,* the 6-MHz channel and the sound and picture carrier assignments within it have survived both the later increase to a 525-line standard in the 1940's (again obsoleting prior receivers) and the addition of compatible color transmission in 1953.

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* "Principles of Television Engineering," D. G. Fink, McGraw-Hill, 1940.

In regard to color, the majority technical opinion up to the late 1940's and early 1950's was that either a wider channel (perhaps 12 MHz) or a slower picture frame rate would have to be adopted in order to transmit each picture frame as three separate, field-sequential red, blue, and green images, as was then thought to be required for reconstruction of a color picture at the television receiver. Indeed, the quite controversial color television standard initially adopted by the FCC in September, 1950, was a field-sequential "color-wheel" system with scanning standards quite different from those in use for monochrome receivers then in the hands of the public. The subsequent intensive industry/government effort which found that it was possible to develop and standardize by December, 1953, a new method of color transmission that fitted the 6-MHz bandwidth and was compatible with the existing monochrome standards was a major engineering feat and finally got color TV off the ground. This dot-sequential system retains the standard monochrome picture modulation as a brightness signal (for either monochrome or color sets), and inserts a third carrier at 3.5795 MHz above the picture carrier to carry all color-related information needed by color receivers, but which can be ignored by monochrome receivers. The only change made in the previous monochrome standards was a 30-50 percent reduction in amplitude of the sound signal relative to the picture signals so as to reduce the possibility of any interference of the sound signal with the color carrier (the sound carrier and the new color carrier are only separated by 0.93 MHz in frequency). The final transmission standard which is in use today is shown in Fig. A-1.

The gist of the above is that in the period 1937-1953, three major modifications were made in U. S. television transmission techniques to raise picture quality and add color, and by improved know-how and clever engineering, each of these modifications was accomplished without changing the basic 6-MHz channel bandwidth that had been chosen in the early 1930's for quite different transmission techniques. That is not to say, however, that all aspects of the present U. S. television standards are necessarily what one would now choose if it were ever

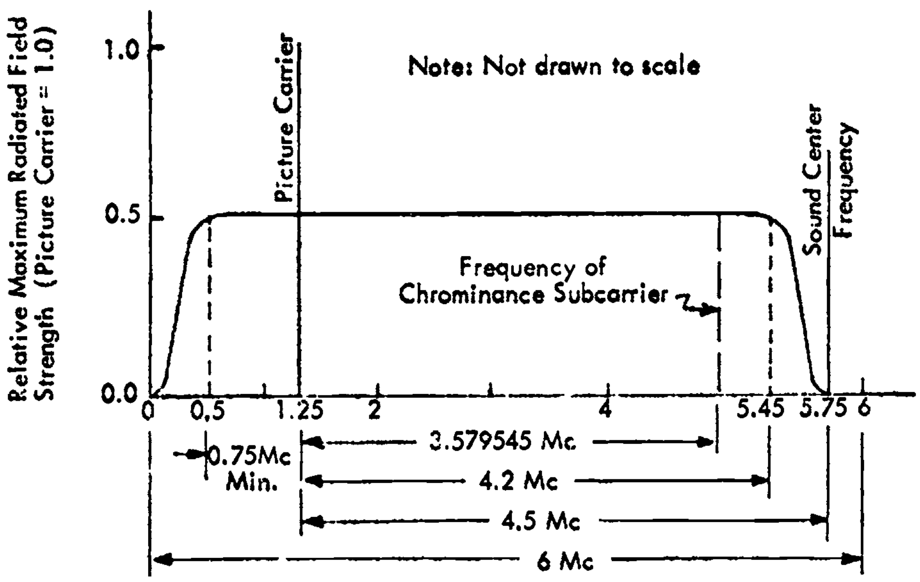

Fig. A-1 The NTSC Color Television Channel

System	No. of Lines	Ch. width MHz	Vision bandwidth MHz	Vision/sound separation MHz	Vestigial sideband MHz	Vision modulation	Sound modulation
A	405	5	3	-3.5	0.75	Pos.	AM
B	625	7	5	+5.5	0.75	Neg.	FM
C	625	7	5	+5.5	0.75	Pos.	AM
D	625	8	6	+6.5	0.75	Neg.	FM
E	819	14	10	± 11.15	2	Pos.	AM
F	819	7	5	+5.5	0.75	Pos.	AM
G	625	8	5	+5.5	0.75	Neg.	FM
H	625	8	5	+5.5	1.25	Neg.	FM
I	625	8	5.5	+6	1.25	Neg.	FM
K	625	8	6	+6.5	0.75	Neg.	FM
L	625	8	6	+6.5	1.25	Pos.	AM
M	525	6	4.2	+4.5	0.75	Neg.	FM
N	625	6	4.2	+4.5	0.75	Neg.	FM

Notes:
1. Field frequency: System M, 60 cycles per second, all other systems 50 cycles per second.
2. Picture frequency: System M, 30 cycles per second, all other systems 25 cycles per second.
3. Line frequency: System A, 10.125 kHz, systems E and F, 20.475 kHz, system M, 15.75 kHz, all other systems, 15.625 kHz.
4. U.S. standard is system M.
5. From C.C.I.R. Report 308, Xth Plenary Assembly, Geneva, 1963.

Fig. A-2 Characteristics of Television Systems in Use Throughout the World possible to make a change. Three-quarters of the countries in the world have opted for better picture resolution by adopting higher line counts (625 or 819 lines), higher picture frequencies (5 or 6 MHz) and wider channels (7 or 8 MHz), although the one-quarter of the countries using U. S. standards account for over half the world's TV sets (132 million out of the total 254 million).*

Figure A-2 shows the characteristics of the television systems in use throughout the world. System M, the U. S. 525-line, 6-MHz standard is used in most of the Western Hemisphere, and in Japan, the Philippines, Okinawa, Korea, Taiwan, Cambodia, and Vietnam. Three countries (Bolivia, Jamaica, and the Barbados) use 625 lines in a 6-MHz channel bandwidth by using 25 instead of 30 picture frames per second (System N), which increases vertical but not horizontal resolution (maximum picture frequency is still 4 MHz). The 405-line, 5-MHz standard (System A) is used only in Hong Kong (a closed-circuit system) and in parts of Ireland and the U.K. The 14-MHz System E is quite wasteful of spectrum space and is used in only three countries (France, Algeria, and Monaco), but France and Algeria also use Systems L and B respectively for at least half their stations. Most other countries in Europe, Asia, and Africa use Systems B, D, or G.

3. The VHF Channel Allocations

In the original allocation of transmission frequencies for television in 1937, the FCC adopted the standard 6-MHz channel width and set aside 19 television channels as shown in Table A-I, although only the eight lowest were considered technically feasible within the radio art of the day.** Three years later, an FCC revision reallocated the 44-50 MHz channel to FM broadcasting and added 60-66 MHz as a television channel (FM was to be later moved to 88-108 MHz). Although these 1940-vintage channels were allocated in pairs, separated mostly by 6- or 12-MHz frequency gaps assigned to other services (government,

* Derived from data in 1970-1971 Television Factbook No. 40.

** D. G. Fink, Ibid.

Table A-I
1937-1940 Television Channel Allocations

MHz	Present VHF or Cable Channel	Notes
44-50		Reassigned to FM June 1940
50-56		
(60-66)	3	Added in June, 1940
66-72	4	
78-84		88-108 is present FM broadcast band
84-90		
94-102		
102-108		
156-162	(G)	Present mid-band cable usage
162-168	(H)	
180-186	8	
186-192	9	
204-210	12	
210-216	13	
234-240	(M)	Present super-band cable usage
240-246	(N)	
258-264	(P)	
264-270	(Q)	
282-288	(T)	
288-294	(U)	

amateur, police, etc.), the basic pattern of the present VHF channel allocations was beginning to emerge, and six of the channel allocations (the present Channels 3, 4, 8, 9, 12, and 13) are still the same. It is also interesting to note that most of these 1937 frequency allocations that did not become part of the final post-war VHF-TV allocations are identical with presently accepted mid- and super-band (letter) channels for CATV (156-168 MHz, and those above 234 MHz).

The FCC again revised the frequency allocation charts in the mid-1940's to create the present lineup of VHF television Channels 2-13 (see Table A-II), at the same time moving the FM broadcast band from 44-50 to 88-108 MHz. One of the factors in these final frequency shufflings was a desire to choose the television channel frequencies so as to avoid as much as possible four types of potential interference in home receivers (other than adjacent-channel) that can be caused by particular relationships among channel transmission frequencies: interference from local oscillator radiation (leakage) by neighboring TV receivers, image interference, intermodulation interference, and IF beats. These interference effects which are described in Section 4 below, were almost completely eliminated in the VHF allocations because of the way the channels are grouped into two isolated blocks of 6 and 7 channels each, separated by a large frequency band (86 MHz, equivalent to over 14 channels). Note that except for Channels 5 and 6, the VHF channel boundaries are all integer multiples of 6 MHz, the channel bandwidth (Channel 5 is offset from Channel 4 by an intervening 4-MHz band assigned to radio services). As will be explained in Section 6, a uniform integer-multiple pattern is highly desirable in multi-channel systems, and the present FCC frequency assignments for Channels 5 and 6 represent a problem in broadband cable TV.

4. Inter-Channel Interference Problems

This section discusses four types of interchannel interference that can be directly created within the circuits of a television receiver as a result of its operation in an environment of TV signals on channels other than the one to which it is tuned—adjacent channel interference, image

Table A-II

Present VHF Television Channel Allocations

VHF Channel Number	Frequency Band	Picture Carrier	Receiver Local Oscillator	Receiver Image Band	Channel in Image Band (Beat freq.)
2	54-60	55.25	101	148-142	
3	60-66	61.25	107	154-148	
4	66-72	67.25	113	160-154	
5	76-82	77.25	123	170-164	
6	82-88	83.25	129	176-170	7(-.5)
7	174-180	175.25	221	268-262	
8	180-186	181.25	227	274-268	
9	186-192	187.25	233	280-274	
10	192-198	193.25	239	286-280	
11	198-204	199.25	245	292-286	
12	204-210	205.25	251	298-292	
13	210-216	211.25	257	304-298	

Note: All frequencies in MHz

interference, intermodulation interference, and "IF" beats — and one that can be indirectly created by local oscillator radiation from neighboring TV receivers. All of these are related both to the particular frequency relationships among the TV channels and the receiver intermediate (IF) frequency, and to the quality of receiver design (shielding, filtering, etc.). Except for the adjacent-channel problem, these have not been of much concern in VHF television reception because of the particular choice of channel frequencies, but they are all of concern in augmented-channel cable systems using mid- and super-band channels, as will be discussed in Subsections (a) through (e) below. They also have all been taken into account by the FCC in its rather stringent rules for geographic isolation of UHF-TV channel assignments, and as will be illustrated in an interesting example given in Subsection (f), have led to rather inefficient use of the UHF spectrum.

a. Adjacent-Channel Interference

As has been discussed in Section 2, the transmitted television signal contains three separate pieces of information (picture, color, and sound) modulated onto three different carriers within the 6-MHz channel (see Fig. A-1), and the receiver must sort these out as cleanly as possible by means of appropriate filters, as well as reject all spurious out-of-band signals.

Filter technology is such that it is difficult to achieve sharp, distortion-free boundaries between an accepted and a rejected band of frequencies, particularly if one is trying to hold circuitry costs to a minimum as in the majority of home TV receivers. Thus in order to satisfactorily pass the desired band of picture frequencies, most TV receivers accept some transmission of frequencies beyond the edges of this band. Note however that for any particular channel within a contiguous group of channels, the sound carrier frequency for the next lower channel is only 1.5 MHz below the picture carrier of the desired channel, and the picture carrier of the next higher channel is only 1.5 MHz above the sound carrier of the desired channel, both rather close so far as band-pass filtering technology goes.

However, since these adjacent carriers are discrete interference sources and their exact relative frequencies are known, additional, narrow-band rejection filters called "traps" are used in most (but not all) TV sets to improve adjacent-channel interference rejection.

Figure A-3 shows typical picture IF response curves measured for several monochrome and color receivers.* Note that color set "A" includes strong frequency traps for the lower-adjacent and the in-channel sound carriers, and for the upper-adjacent picture carrier. Color set "B" also has traps but has substantially (28 dB) less protection against the in-channel sound and the upper-adjacent picture carriers, and 10 dB less against the lower adjacent sound carrier (note also that the monochrome sets, which don't need to protect the 3.5795-MHz color carrier, don't bother with traps for the in-channel sound carrier). The point here is that adjacent-channel rejection characteristics vary widely from set to set, not only as originally manufactured, but perhaps even more so as circuitry ages and gets out of adjustment (i.e., trap filters may shift in frequency). Rejection characteristics also vary as a function of signal levels.

Recognizing the difficulty of designing receivers to properly cope with strong adjacent-channel signals over their useful life, the FCC has followed a strict policy of never assigning adjacent channels to TV transmitters separated by less than 60 miles at VHF, or 55 miles at UHF. Of course many receivers are located such that they are able to pick up stations on adjacent channels, but because of the above separation rule, one of the signals will usually be weaker than the other and not interfere with the stronger one. When objectionable interference is encountered (perhaps in trying to view a distant station), many set owners are able to use a directional antenna to strengthen the desired signal relative to a stronger undesired one.

In CATV, adjacent-channel transmission is the norm and cable systems must thus be carefully engineered and maintained both to keep

* From "Supplemental Comments of National Cable Television Association (NCTA)" on FCC Docket No. 18894, January 6, 1971.

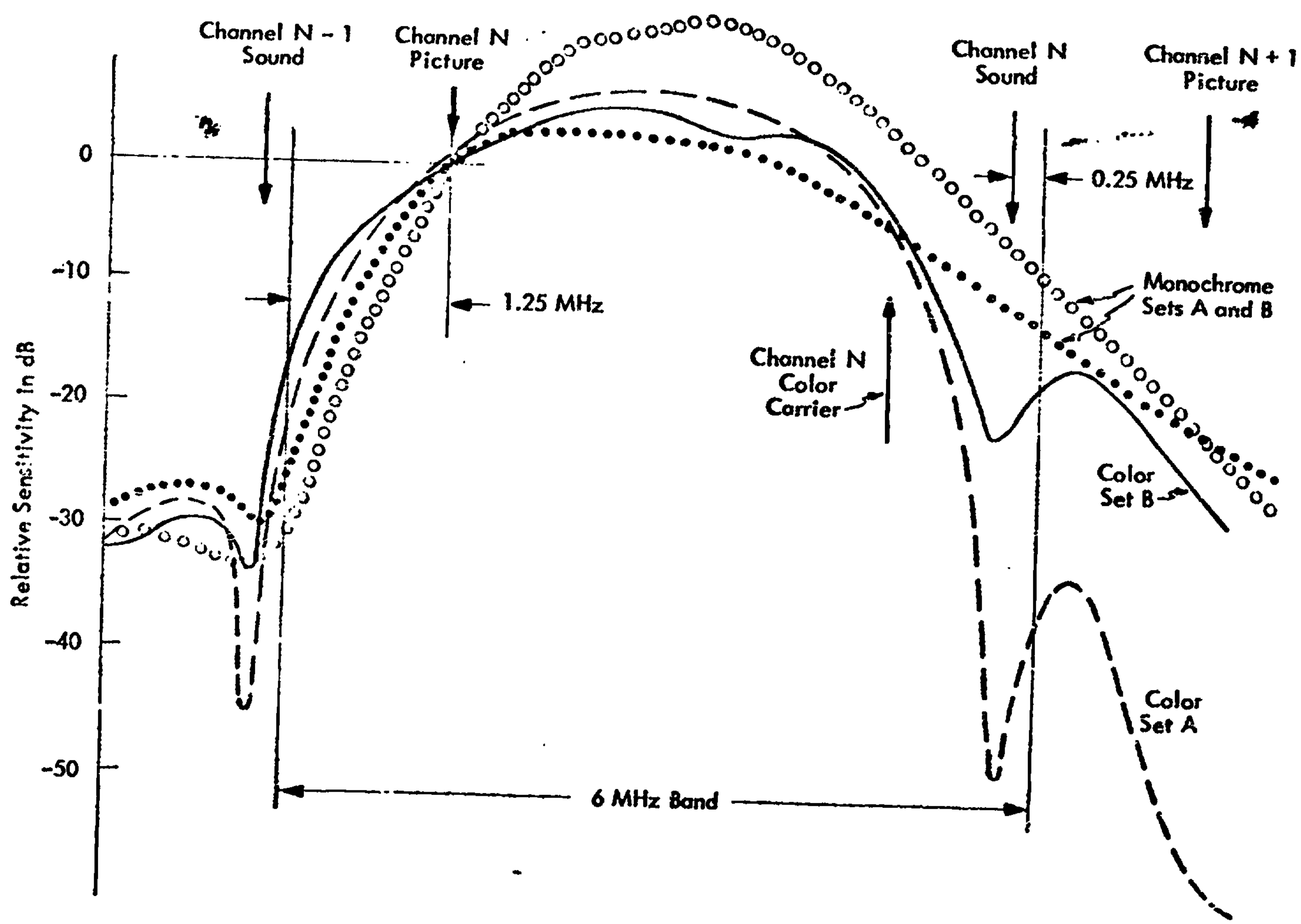

Fig. A-3 Picture-IF Selectivity Characteristics of Typical Television Receivers
(From NCTA Supplementary Comments to FCC, Jan. 6, 1971)

all signal levels balanced with respect to one another and at an optimum overall level at each subscriber's tap. The sound carriers have given particular trouble, and most cable systems have had to keep them at lower levels relative to the picture carriers than prescribed by the FCC for broadcast-TV, leading to marginal sound on some receivers. Where individual receivers give trouble, they may require special adjustment or even modification or replacement. (See footnote on page 3-4.)

b. Oscillator Radiation

The oscillator interference problem is as follows. Each TV receiver acts like a little transmitter, radiating a small amount of power from its local oscillator at a frequency which depends on the channel to which the receiver is tuned. This radiation can escape either back through its antenna (or into the CATV cable), into the a-c power line, or directly from the receiver chassis. If the oscillator frequency for one channel falls within the frequency limits of another higher channel, and two neighboring TV receivers are respectively tuned to these particular channels, the oscillator radiation from the receiver tuned to the lower channel might be strong enough to be picked up as a spurious signal at the neighboring receiver and interfere with its reception of the higher channel. The first four columns of Table A-II (page A-9) show the 12 VHF channels, their transmitted picture carriers and the frequencies to which a receiver local oscillator must be tuned to receive each channel.* Note that none of the local oscillator frequencies for Channels 2 - 13 fall within the transmission band of any other channel and thus no particular safeguards were necessary either in geographic assignments of VHF stations or in stringent limits on oscillator leakage from VHF receivers. The only possible oscillator problem in the VHF allocations is that the second harmonics of the oscillator frequencies for Channels 2

* The current standard intermediate frequency (IF) amplifier pass-band for picture signals is from 41.5 to 46.5 MHz, and the oscillator is always tuned 45.75 MHz above the desired picture carrier. Pre-war, the IF pass-band was 8.5 to 12.75 MHz, and the oscillator was tuned 12.75 MHz above the desired picture carrier. Post-war, an IF frequency pass-band of 21.5-26.5 MHz was standard for a period, with an oscillator offset of 25.75 MHz, and some of these receivers are still in service.

and 3 fall within the bands of Channels 11 and 13, respectively, but second- and third-harmonic radiation is generally 10-20 dB weaker than the direct oscillator radiation in any given receiver.

Although oscillator radiation interference is not a problem within the 12 VHF channels because of the way in which the channels are allocated, it is a problem in both UHF-TV and in cable systems using mid- and super-band channels. As will be discussed later, many oscillator/channel overlaps occur in both these cases and means must be taken to keep oscillator interference below troublesome levels.

c. <u>Image Interference</u>

Image interference in any superheterodyne radio or TV receiver is caused by the fact that the mixing of the local oscillator signal with incoming radio-frequency signals to convert the desired signals to the IF frequency band for amplification can also create a number of other sum and difference frequencies. As noted above, the television standard is that desired frequencies are <u>lower</u> than the receiver oscillator frequency, and the IF amplifier accepts the frequency band equal to the oscillator frequency minus the frequency limits of the desired channel. However, the mixer also creates the same band of difference frequencies if any incoming signals present at its input are the same amount <u>higher</u> than the oscillator frequency, thus the term "image". Good receiver design dictates that the input radio frequency circuits (part of the channel tuner) discriminate against image reception by passing only the desired channel frequencies and rejecting all others, thus preventing any significant input signal energy in the image frequency band from ever reaching the heterodyne mixer. The extent to which this goal is achieved in a particular receiver (or CATV converter) design is called its "image rejection ratio".

The fifth column in Table A-II (page A-9) shows the receiver image band for each VHF channel. Note that the channel frequency relationships are inverted in image reception, and that to receive a correct picture on an image frequency the picture carrier would have to be 1.25 MHz below the upper image band edge, with the picture modulation band extending downwards. Thus the image frequency range for objectionable interference beats for any channel is from perhaps 0.75 to 2.75 MHz below the upper edge of its image band. Only one potential image problem exists in the VHF-TV allocations — Channel 7 partially overlaps the image band for Channel 6. In this case, however, the Channel 7 picture carrier is 0.5 MHz above the image frequency of the Channel 6 picture carrier, thus any signal energy resulting from image reception of Channel 7 when viewing Channel 6 will appear in the lower sideband of the true Channel 6 signal and be attenuated at least 10 dB in the IF amplifier (see Fig. A-3). This is called a "negative" beat and should cause no trouble, except in receivers with very poor image rejection characteristics, but even so, the FCC has apparently tended to avoid allocation of both Channels 6 and 7 in the same market (there are currently only four cases of 6-7 broadcast co-allocation: Denver, Miami, Omaha, and Spokane). Channels 6 and 7 have been routinely carried side-by-side in traditional 12-channel cable systems, however, apparently with little or no trouble. The inference here is that most TV receivers have image rejection characteristics that are satisfactory, at least in regard to this particular "negative" image beat between Channels 6 and 7. However, "positive" in-band image beats can occur when mid- and super-band channels are added, and the channel converters for such augmented cable systems must be designed to cope with them.

The above discussion has considered only image interference from picture carriers. Each TV signal also carries significant energy in its sound carrier located 4.5 MHz above the picture carrier. With an oscillator offset of 45.75 MHz, image interference from a sound carrier affects the next higher channel than the one affected by its associated picture carrier. For example, the picture and sound carriers for mid-band cable Channel E (144-150 MHz) are at 145.25 and 149.75 MHz respectively. The following shows the spurious IF signals which these can create in image reception:

Receiver Tuned to Channel	Oscillator Frequency	IF Signal from Channel E Picture Carrier	IF Signal from Channel E Sound Carrier
2	101	44.25	48.75
3	107	38.25	42.75

Since the receiver IF pass-band is from 41.25 to 46.5 MHz, the Channel E picture carrier image can affect Channel 2, and the sound carrier image Channel 3. The other two beats are outside the IF pass-band.

Finally, it should be noted that any given channel can appear as an image to lower channels, at the same time that higher channels appear as an image to it. Thus image relationships to be considered in contiguous channel blocks with 6-MHz spacing are ±15 channels (picture carrier image) and ±14 channels (sound carrier image). These will be discussed further in Section 6.

d. Intermodulation

Intermodulation is a term describing the interaction of signals on different frequencies to create various sum and difference signals on other frequencies. There is no mechanism for such interaction as signals propagate through the air, but it can and does occur when multiple signals pass through any circuitry containing active elements (amplifiers, mixers, detectors, etc.). Thus in broadcast TV, the presence at the receiver antenna of multiple station signals on various carrier frequencies results in some unavoidable interaction between them in the receiver circuitry, which can create visible picture interference depending on the frequencies of the intermodulation products, and their strength (which depends on the quality of the receiver design).

The most troublesome (but not the only) intermodulation effect is the third-order beat involving the second harmonic of one interfering signal minus the frequency of another interfering signal. Take for example VHF Channels 9 and 11 (picture carriers 187.25 and 199.25 MHz). The two possible third-order beats between these two carriers fall precisely on the picture carriers of other channels:

$$2(187.25) - 199.25 = 175.25 \text{ MHz (Channel 7)}$$
$$2(199.25) - 187.25 = 211.25 \text{ MHz (Channel 13)}$$

A Channel 7 Beat is also produced by the combinations 8-9 and 10-13, and a Channel 13 beat by 7-10 and 11-12, but 8-9 and 11-12 problems are unlikely in broadcasting because of the non-adjacent-channel rule.

Another important but apparently less troublesome intermodulation effect is the second-order beat involving one frequency plus or minus another one. For example, 140 MHz can be produced by 60 plus 80, or 220 minus 80.

The intermodulation performance of receivers at VHF frequencies is generally good enough that no special precautions against it were necessary in VHF station assignments (7-9-11-13 is a common co-market assignment pattern). In cable systems, however, these intermodulation products can be created in the cable system itself since all VHF channels are carried side-by-side through various head-end and cable amplifiers. Here again, careful design and maintenance of the cable system is necessary, particularly as additional mid- and super-band channels are added and the total bandwidth of the amplified frequencies is increased.

e. <u>IF Beats</u>

A particular form of second-order intermodulation called an "IF beat" results if two channels separated approximately by the receiver IF frequency (45.75 MHz) should somehow interact in the circuitry of a receiver to create difference frequencies at the input to the IF amplifier that fall within its passband and will be amplified along with the desired IF signal. The most probable such situations are the beats between the desired channel and the ones located 7 and 8 channels above and below it in frequency. This cannot occur in the frequency assignment pattern of Channels 2 through 13, but can in UHF-TV and in cable systems using mid- and super-band channels in addition to the VHF channels. UHF-TV avoids the problem by geographic isolation of IF-beat channels (see below). Cable systems will either have to live with it, or as some people now think, design cable converters or special cable receivers with a much higher IF frequency. This would also help the oscillator leakage and image problems.

f. Application of Anti-Interference Rules in UHF-TV

Although UHF transmission and reception are not of concern in cable systems, the cumulative effect of the above mutual interference problems in large blocks of contiguous television channels are perhaps best illustrated by the UHF "taboos" (non-co-assignment rules for UHF channels based on the possibility of mutual interference). In a recent paper proposing a new look at the question of geographic/frequency allocations,* Norman Parker (Motorola) traces the history of the UHF "taboos" and gives the following example. If a particular UHF channel, say No. 29, is assigned in a given area, FCC rules state that a total of 18 other UHF channels cannot be assigned to transmitters operating within distances ranging from 40 - 120 miles from the Channel 29 transmitter. These channels, their potential interference effect, and the minimum mileage separations are shown below:

Relative Channel Spacing	Actual Channels Idled if Channel 29 is assigned	Type of Interference Potential	Minimum Separation Radius
±1	28, 30	Adjacent channel	55 miles
±2, 3, 4, 5	24, 25, 26, 27 31, 32, 33, 34	Intermodulation	40 "
±7	22, 36	Oscillator	120 "
±8	21, 37	IF beat	40 "
±14	15, 43	Sound image	120 "
±15	14, 44	Picture image	75 "

*"A Proposal for the Modernization of the UHF Television Taboos", Norman Parker, presented at the IEEE-PGVT Conference, Washington, D. C., December 2, 1970.

This process is of course repeated for each channel. Thus in any 31-channel span of frequencies, almost 60 percent of the channels can cause interference to (receive interference from) the one in the center of the span, and their use is restricted as above for UHF broadcast purposes. Although the above "taboos" were adopted by the FCC at a time (1952) when the design of UHF-TV receivers was in its infancy and were deliberately ultra-conservative, they are still in effect. Part of Mr. Parker's thesis is that in the light of modern UHF-receiver performance, some of these could perhaps now be relaxed. They still are good blueprint however for potential inter-channel interference problems in 20-40 channel cable systems, particularly since the cable system itself represents an additional mechanism for the generation of intermodulation products.

5. Other Interference Problems Peculiar to Cable

The inter-channel interference problems described in Section 4 above occur in both broadcast-TV and cable-TV and are all generated in or by television receivers as a result of the interaction of receiver design parameters and particular channel-frequency relationships. As has been discussed, their deleterious effect on received pictures can be eliminated or reduced (at least below levels discernible to the viewer) by some combination of proper receiver/converter design, proper choice of channel frequencies and transmission standards, and in broadcasting, by geographic isolation of troublesome station frequency assignments. There are two other interference problems that are peculiar to cable systems and have somewhat different impact on cable and receiver engineering and the choice of cable frequencies: co-channel interference with cable signals by broadcast TV signals, and possible interference of cable signals, should they escape from the cable, with other radio services. These are described below.

a. Co-channel Interference by Broadcast Signals

In the early days of cable-TV, systems were usually installed where there were no strong local television stations, and programs were generally carried on the cable on the same channels on which they were broadcast.

As cable expanded into areas nearer the stations, it was found that with such on-channel carriage, many subscribers were troubled by interference caused by dual reception of the same program: a direct, unwanted signal leaking into the cable or their receiver from the broadcast station, and the same signal as picked up by the cable system antenna, processed by the cable head-end, and transmitted through the cable. Because the cable signal travels a greater distance, at least part of which is through a slower medium (1.2 usec per 1,000 feet in the cable as opposed to 1 usec per 1,000 feet through the air), the interfering direct-pickup signal arrives first and creates various effects depending on its strength relative to the cable signal and the relative signal delays. Particular effects in received pictures are "left-hand ghosts", vertical black synch bars, or random stripe patterns.

As a result of the on-channel carriage problem, it has been common cable practice to carry strong local stations on different "quiet" channels on the cable. This represents both an inconvenience for the subscribers (these stations are not found at their normal positions on the dial), and a wastage of channel capacity. In some metropolitan areas with many local stations, as many as five or six cable channels are unusable because of on-channel interference, leaving only six or seven channels in what should be a 12-channel cable. It was this problem that has prompted the installation of many dual-cable systems (with subscriber "A/B" selector switch) to increase capacity, but note that the same interference rules apply to both cables and some dual-cable systems can still offer only 12-14 channels.

Broadcast signals can leak into any part of the cable system (up to and including the final connection to the antenna terminals of a subscriber receiver), or directly into the receiver itself via pickup in its internal wiring or circuits (note that on-channel leakage is of little concern in broadcast reception). On-channel leakage pickup into the cable system is susceptible to correction in a large number of cases by careful engineering and installation; the methods for this have been described by Archer Taylor.* However, in this same article, Mr. Taylor also states:

* "On-Channel Carriage of Local TV Stations on CATV", Archer S. Taylor, IEEE Transactions on Broadcasting, Vol. BC-5, No. 4, Dec. 1969, pp. 102-104.

"Where cable subscribers are located less than about 10 miles from a local TV transmitting antenna, it is probable that nothing short of modification of the TV receiver will cure some cases of direct pickup." .... "In the final analysis, the best answer is the redesigning of TV receivers so that they are isolated (shielded) from ambient fields. Work on this is in progress. We stand a better chance of success when we have 20 million subscribers than we do with 3 1/2 million (1969)."

These comments of course apply to cable systems in which receivers are directly connected to the cable, i.e., without use of subscriber (set-top) converters. It would probably take at least 10 years to turn over the present inventory of sets in use, even if only shielded sets were to be produced from now on.

When certain (but not all) types of converters are used, the receiver is left tuned to a "quiet" VHF channel, eliminating any co-channel problem in the receiver. However, the converter must then be designed with sufficient shielding to prevent co-channel interference effects within it, but this is relatively easy to do and the requirement is clear-cut, which it hasn't been for TV receivers. At the same time, converters can be designed to avoid all of the inter-channel interference effects described in Section 4.* In this regard it is interesting to note that the first CATV converter appeared less than six years ago, and that the number in service is still quite small (in the tens of thousands). Most of these have been largely assembled from standard TV tuner components, modified only for the new channel frequencies, and it is only recently that more than cursory attention has been paid to the possibilities afforded by new designs optimized for broadband cable purposes.

*"Design and Use of CATV Converters", Patrick K. J. Court, Information Display, March/April 1971. See also M. F. Jeffers letter March 4, 1971, (page

b. Cable Interference with Other Services

The signals carried in a cable system are at radio frequency and thus are quite capable of propagating in all directions through the air if not properly confined within the coaxial cable and shielded equipment boxes which form the system. Although the cable signal levels are quite low compared to those normally applied to the antenna of a transmitter, they can still create significant field intensities (and thus interference) up to a few thousand feet from the cable in the case of the worst possible type of shielding break — one that somehow acts as a perfectly efficient isotropic antenna and is located immediately following a cable amplifier where the signal levels are highest.* Even without a major cable fault of this sort, cable systems can never be perfectly shielded and there will always be some radiation, even if it is only detectable within a few feet of the cable.

Radiation from a cable system carrying only the 12 standard VHF channels should of course cause interference only with television reception, and only in receivers located nearby. However when additional mid- and super-band frequencies are carried, cable radiation could possibly affect other radio services as follows:

Mid-Band

88-108 MHz —	FM Broadcast (may actually be carried on the cable)
108-136 MHz —	Aeronautical
136-144 MHz —	Government, Space Research, Meteorological
144-148 MHz —	Amateur
148-151 MHz —	Radionavigation
151-174 MHz —	Land-Mobile, Maritime, Government

Super-Band

216-225 MHz —	Government, Amateur
225-329 MHz —	Government

* "Possible Radiation from Broken CATV Cables in the 118-136 MHz ATC Band", J. E. Adams, Jan., 1971 (Informal working paper prepared for the Office of Telecommunications Policy, and circulated to the IEEE Spectrum Allocation Subcommittee).

The FCC has long recognized the problem of cable radiation, and specifies in subpart D, Section 15.161 on "Radiation from a Community Antenna Television" of its Rules and Regulations:

Radiation from a community antenna television system shall be limited as follows:

Frequencies (MHz)	Distance (feet)	Radiation Limits (micron v/m)	
		General requirement	Sparsely inhabited areas[1]
Up to and including 54	100	12	15
Over 54 up to and including 132	10	20	400
Over 132 up to and including 216	10	50	1000
Over 216	100	15	15

[1] For the purpose of this section, a sparsely inhabited area is that area within 1000 feet of a community antenna television system where television broadcast signals are, in fact, not being received directly from a television broadcast station.

Although not immediately apparent because of the fact the specified distances are not all equal, the protection in the band between 54 and 216 MHz is considerably higher than for frequencies above and below it. Note also that permissible levels are much higher in the TV bands (and mid-band) in areas remote from TV stations where every TV receiver is expected to be on the cable and not using an antenna.

Now that substantial use is beginning to be made of mid- and super-band transmission on cable systems, the FCC and the FAA among others have become concerned about potential interference dangers with the radio services that are listed above, particularly the aeronautical (ATC) services. One situation postulated is that an aircraft in taking off or making a landing approach may fly quite low over a CATV cable at the same time that it is a considerable distance from the ATC transmitter. If the cable were faulty and radiating at the ATC frequency, the resulting interference at the aircraft receiver might have critical consequences.

even though the time exposure to it would be brief (of the order of 40 seconds maximum). One analysis to date concludes that this should not be a serious problem, but that certain safeguards should perhaps be established:*

(1) adoption of upper signal level limits for CATV cables,

(2) installation of break-detection devices in all cable systems,

(3) placement of mid-band CATV carrier frequencies between ATC channels.

This subject is just coming under intensive study and discussion by the FCC, the FAA, the Offices of Telecommunications and Telecommunications Policy, the IEEE Cable Television Task Force Committee, and others, as part of the current debate on cable standards. The intent here is not to shed any light on the solution, but only to point out that this question adds another dimension to the cable frequency allocation problem, and that the ultimate decisions, particularly in regard to item (3), may have a deleterious effect on the channel capacity of future systems.

6. The Cable Channel Allocation Question

So long as cable systems simply carried television signals on the same channel frequencies assigned by the FCC for VHF broadcasting, the only two of the six interference effects discussed in Sections 4 and 5 above that represented any real problems for cable operators were adjacent-channel interference and on-channel pickup; the former handled by careful signal balancing and level-control, and the latter by idling the troublesome channels.** However, as new cable channels

* J. E. Adams, Ibid

** "The Real World of Technological Evolution in Broadband Communications", Hubert J. Schlafy, Report prepared for the Sloan Commission on Cable Communications, September, 1970.

began to be added in a few systems starting about 1968, all of the effects applied, initiating a debate which has just reached full intensity in the past few months, and in which this study has had a small measure of involvement. The following are indicative of the questions now under consideration.

a. A Non-Contiguous Channel Scheme

In a paper presented at the 1970 NCTA National Convention, M. E. Jeffers (Jerrold Electronics Corp.) set forth the oscillator and image beat effects in the generally accepted mid- and super-band assignments (shown by the boxes in the last two columns of Table A-III) and proposed a realignment of the mid- and super-band cable-channel assignments to eliminate these problems.* His proposal for realignment was to alter the band limits for the mid- and super-bands and insert frequency offsets between these channels at appropriate points, with the objective of placing all oscillator and image beats at band-edge (between channels) where their interference effect would be minimal.

Since the new channel assignment charts in Mr. Jeffers' paper did not cover the entire 54-300 MHz cable spectrum, an overall chart based on his mid- and super-band assignments was prepared as shown in Table A-IV. This gave the total channel count (35), but also brought to light the fact that because of the complexity of the inter-channel relationships, it is almost impossible in such a frequency juggling exercise to avoid creating new problems while trying to correct other ones. For example, Mr. Jeffers was successful in placing all mid-band/low-VHF-band and super-band/high-VHF-band image and oscillator beats at band edge, but in the process created three dead-beat images of super-band channels on mid-band channels and five undesirable ("positive") oscillator beats on high-VHF band channels by mid-band channels, as shown by the boxes in the last two columns of Table A-IV.

*"Best Frequency Assignments for Mid- and Super-Band Channels", Michael F. Jeffers. (Included as Exhibit C in Supplemental Comments of NCTA on FCC Docket No. 18894, January 6, 1971.)

Table A-III

Present VHF, Mid-Band, and Super-Band Assignments

Channel		MHz	Video Carrier	Osc. Freq.	Image Freq.	Channel Affected by Osc.	Video Carrier on Image Frequency
2		54-60	55.25	101	146.75		E (1.5)
3		60-66	61.25	107	152.75		F (1.5)
4		66-72	67.25	113	158.75		G(1.5)
		10					
5		76-82	77.25	123	168.75	A (1.75)	-
6		82-88	83.25	129	174.75	B (1.75)	7 (-.5)
		32					
A	MID-BAND	120-126	121.25	167	212.75	H (3.75)	13 (1.5)
B	MID-BAND	126-132	127.25	173	218.75	I (3.75)	J (1.5)
C	MID-BAND	132-138	133.25	179	224.75	7 (3.75)	K (1.5)
D	MID-BAND	138-144	139.25	185	230.75	8 (3.75)	L (1.5)
E	MID-BAND	144-150	145.25	191	236.75	9 (3.75)	M(1.5)
F	MID-BAND	150-156	151.25	197	242.75	10 (3.75)	
G	MID-BAND	156-162	157.25	203	248.75	11 (3.75)	
H	MID-BAND	162-168	163.25	209	254.75	12 (3.75)	
I	MID-BAND	168-174	169.25	215	260.75	13 (3.75)	
7		174-180	175.25	221	266.75	J (3.75)	
8		180-186	181.25	227	272.75	K (3.75)	
9		186-192	187.25	233	278.75	L (3.75)	
10		192-198	193.25	239	284.75	M(3.75)	
11		198-204	199.25	245	290.75	↑	
12		204-210	205.25	251	296.75	3.75 MHz	
13		210-216	211.25	257	302.75	is a color	
J	SUPER-BAND	216-222	217.25	263	308.75	beat	
K	SUPER-BAND	222-228	223.25	269	314.75		
L	SUPER-BAND	228-234	229.25	275	320.75		
M	SUPER-BAND	234-240	235.25	281	326.75		

Table A-IV

Suggested New Mid- and Super-Band Allocations by M.F. Jeffers

Channel		MHz	Video Carrier (6-MHz separations except as noted)	Osc. Freq.	Image Freq.	Channel Affected by Oscillator (Beat Freq.)	Video Carrier on Image Frequency (Beat Freq.)
2		54-60	55.25	101	146.75	-	-
3		60-66	61.25	107	152.75	-	-
4		66-73	67.25	113	158.75	-	-
			---10				
5		76-82	77.25	123	168.75	B(-1.25)	-
6		82-88	83.25	129	174.75	C(-1.25)	7(-.5)
			---35				
A	JEFFERS CHANNELS	117-123	118.25	164	207.75	H(- .75)	-
B		123-129	124.25	170	215.75	-	-
C		129-135	130.25	176	221.75	7(+.75)	I(-.5)
D		135-141	136.25	182	227.75	8(+.75)	J(-.5)
			--- 6.5				
E		141.5-147.5	142.75	188.5	234.25	9(+1.25)	K(0)
F		147.5-153.5	148.75	194.5	240.25	10(+1.25)	L(0)
G		153.5-159.5	154.75	200.5	246.25	11(+1.25)	M(0)
			---10				
H		163.5-169.5	164.75	210.5	256.25	13(-.75)	O(-2)
			---10.5				
7		174-180	175.25	221	266.75	I(-1.25)	P(-2)
8		180-186	181.25	227	272.75	J(-1.25)	Q(-2)
9		186-192	187.25	233	278.75	K(-1.25)	R(-2)
10		192-198	193.25	239	234.75	L(-1.25)	S(-2)
11		198-204	199.25	245	290.75	M(-1.25)	T(-2)
12		204-210	205.25	251	296.75	N(-1.25)	U(-2)
13		210-216	211.25	257	302.75	O(-1.25)	
			---11				
I	JEFFERS CHANNELS	221-227	222.25	268	313.75	P(-.75)	
J		227-233	228.25	274	319.75	Q(-.75)	
K		233-239	234.25	280	325.75	R(-.75)	
L		239-245	240.25	286	331.75	S(-.75)	
M		245-251	246.25	292	337.75	T(-.75)	
N		251-257	252.25	298	343.75	U(-.75)	
O		257-263	258.25	304	349.75		
			---10.5				
P		267.5-273.5	268.75	314.5	360.25		
Q		273.5-279.5	274.75	320.5	366.25		
R		279.5-285.5	280.75	326.5	372.25		
S		285.5-291.5	286.75	332.5	378.25		
T		291.5-297.5	292.75	338.5	384.25		
U		297.5-303.5	298.75	344.5	390.25		

35 channels

These findings were brought to Mr. Jeffers' attention, and he has agreed with them (see letter next page). However, as indicated in his letter, he feels that these particular problems can be eliminated by proper converter design — either holding oscillator radiation and image rejection to very tight limits, or using a different, very high IF frequency in converters to completely eliminate oscillator and image beats. These measures would not help reduce intermodulation interference effects, which become exceedingly complex with such non-contiguous channel spacing.

b. A Contiguous Channel Scheme

The inter-channel interference effects discussed in Section 4 of this Appendix have long been a factor in the analog frequency-multiplex systems (L_1, L_2, etc.) utilized by the telephone company in its inter-city trunk circuits, and methods have been developed to cope with them. One of these is the careful control of channel frequency ratios, including derivation of all carriers by suitable frequency multiplications from a common master oscillator.

Mr. I. Switzer (Maclean-Hunter Cable TV Limited) has presented a paper advocating use of such techniques in CATV systems.* Mr. Switzer has also corresponded with the author on the mid- and super-band frequency allocation question, advocating a contiguous set of channels at constant spacing to help overcome intermodulation effects (see letters following). If such a plan were carried through completely, Channels 5 and 6 would have to be moved 4 MHz lower in frequency to fit into the plan. This would not be of any consequence in a system where all subscribers have converters or special cable receivers, but would if "dual-class" service is offered, as discussed in Subsection (c) below.

A contiguous-channel allocation scheme would yield a total of 41 CATV channels if the spectrum between 54 and 300 MHz were

* "Phase Lock Applications in CATV Systems", I. Switzer, Presented at NCTA Annual Convention, Chicago, Illinois, June, 1970.

A-29

J. E. WARD MAR 8 1971

ELECTRONICS CORPORATION

ENGINEERING LABORATORY
BYBERRY ROAD AND TURNPIKE, P. O. BOX 37, HATBORO, PENNSYLVANIA

March 4, 1971

Mr. John E. Ward, Deputy Director
Electronic Systems Laboratory
Department of Electrical Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts, 02139

Dear Mr. Ward:

I am in receipt of your letter referring to a possible flaw that you have spotted in my paper, "Best Frequency Assignments For Mid and Super Band Channels."

Your analysis is correct. However, although I did not include the following statement in the printed paper, I did say in my talk at the NCTA Show that the responsibility of avoiding the image and oscillator beats that you refer to fall onto the manufacturer of the Set Converter. Since this unit is fully under the control of manufacturers selling to the CATV industry, specifications can be applied to avoid the problems that you mentioned. In addition, many of the manufacturers of Set Converters today are completely, and very wisely, avoiding this problem by converting to a higher frequency IF between 300 and 400MHz (instead of to the standard 45.75MHz IF), thereby completely avoiding all the oscillator leakage problems and the image problems to which you refer. With either tight specifications placed on all Set Converter manufacturers who use the low frequency IF, or by designing Set Converters using high frequency IF, the problems you address yourself to disappear.

Thank you for your interest, and if there is any more I can do to answer your question, please do not hesitate to call on me.

Very truly yours,

M. F. Jeffers
Vice President - Engineering

rwp
cc/G. Norman Penwell

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A-30

J. E. WARD MAR 5 1971

Maclean-Hunter Cable TV Limited

27 Fasken Drive
Rexdale, Ontario
416 - 677 - 5930
CANADA

March 1, 1971.

Mr. John E. Ward, Deputy Director,
Electronic Systems Laboratory,
Department of Electrical Engineering,
Massachusetts Institute of Technology,
Cambridge, Mass., U.S.A. 02139

Dear Mr. Ward,

Norm Penwell has been kind enough to send me a copy of the letter that you sent him commenting on some apparant deficiencies in Mike Jeffers' suggested mid-band allocation plan.

I participated actively in Canadian government developemnt of cable television technical standards. While firm allocations for mid-band channels in Canada have not yet been made, the subject is being actively discussed. In my comments on mid-band allocation plans I firmly recommended a set of allocations for mid-band and superband that were contiguous with the present VHF high-band allocations.

My reason is that I believe that third order inter-modulation problems are more severe in cable television systems than is generally realized and that the use of a contiguous set of channels permits all the visual carriers to be spaced by a constant 6 MHz derived from a "master oscillator". This is common telephone carrier practice and I believe that such a mode of operation would do a great deal to reduce third order intermodulation interference in cable television systems. Problems of local oscillator and image interference will have to be dealt with by applying tighter specifications to tuners and converters used in such systems. I consider the prospect of intermodulation interference reduction to be a major factor in considering a contiguous allocation scheme.

A further improvement in system performance could be achieved by use of suppressed carrier, i.e. modulation and sideband structure as in present system but with suppression of the carrier. I am sure that practical converters can be developed that would reinsert the carrier for reception on standard television receivers.

Maclean-Hunter Cable TV Limited

A combination of "locked carriers", except perhaps for low band, and suppressed carrier would considerably increase the load handling capability of cable television systems.

More exotic modulation schemes might be considered, such as FM or pulse code techniques, but they require a great deal more bandwidth than the present vestigial sideband technique. Bandwidth on cable is extremely limited and I do not see exotic modulation systems as practical until we have cable transmission capability to 1,000 MHz. Suppressed carrier provides a significant increase in capability without using up spectrum (except perhaps a small notch for a pilot carrier of some kind).

Yours sincerely,

I. Switzer, P.Eng.,
Chief Engineer.

cc G.N. Penwell.

A-32

J. E. WARD MAY 6 1971

Maclean-Hunter Cable TV Limited

27 Fasken Drive
Rexdale, Ontario
416 - 677 - 5930
CANADA

May 3, 1971.

Mr. John E. Ward,
Deputy Director,
Electronic System Laboratory,
Massachusetts Institute of Technology,
Cambridge, Mass., U.S.A. 02139

Dear Mr. Ward,

Thank you for your additional comments on frequency allocation for augmented cable systems. The only maverick channels in the present VHF bands are channels 5 and 6. Channels 2,3,4, fit into a 6 MHz spacing with high band and contiguous mid and super band channels. Most second order beats (i.e. sum and difference products) will also be handled by common 6 MHz spacing. Harmonic products will, of course, not be helped.

I sincerely believe that the matter should be studied and standardized by a committee similar to the National Television Service Committee. I believe that the allocations finally adopted would be contiguous channels, with channels 5 and 6 moved downward 4 MHz to bring them into a workable plan of this kind. I have to make some decision right now and I am betting that this will be the outcome.

I hope to get a budget later this year to actually build a working head end with as many channels as possible locked to common 6 MHz spacing (excepting 5 and 6). I will also try and elaborate the "theory" associated to see whether the actual channel spacing should not be very accuratly controlled as a multiple of "colour scanning frequency", 15.734 KHz, so that beats falling into 5 and 6 might, as much as possible, fall onto the normal spectral lines and thus look like sync pulse components. This would be analogous to reasoning behind precision offset operation criteria.

Yours sincerely,

I. Switzer, P.Eng.,
Chief Engineer.

IS/is

completely filled. As has been discussed, some frequencies in this range may be unusable for CATV if it is determined that a serious interference hazard exists with other services, particularly with aeronautical radio-navigation aids in the 108-136 MHz band.

c. Dual Service Class Considerations

One factor which additionally complicates the whole frequency allocation issue is the fact that many operators may desire or need to offer two classes of compatible service on the same cable: VHF-only at one price for subscribers standard receivers and no converters, and VHF plus cable channels at a higher price for subscribers using converters or special cable receivers. Thus a channel-utilization scheme which depends primarily upon the ability of converters or special cable receivers to eliminate interference effects might be unacceptable for such dual-class service — those standard TV receivers that are directly connected to the cable might not be able to cope with interference beats resulting from the presence of non-VHF cable channels. Here an allocation scheme that provides additional protection to the VHF-TV channels may be required, such as the proposal by M. F. Jeffers discussed in Subsection (a) above. On the other hand, the optimum solution for broadband cable service may turn out to involve relocation of the present VHF Channels 5 and 6 downward by 4 MHz to fit into a contiguous channel allocation scheme as discussed in Subsection (b) above, and a non-converter subscriber to such a system would be unable to receive Channels 5 and 6 and be "channel poor". Current discussions include the possibility that there may have to be several alternate cable-frequency allocation standards to fit different situations,* but this would be unfortunate from the point of view of cost-effectiveness in equipment manufacture and interchangeability or portability of equipment from system to system. Eventual large-scale production of augmented-channel TV sets for cable use would seem to depend upon having a single nationwide standard, such as now exists for broadcast-TV.

* Minutes of Cable Spectrum Allocation Subcommittee, Cable TV Task Force, IEEE, January 2, 1971.

APPENDIX B

The Rediffusion Switched
TV Distribution System

This appendix consists of two parts. The first part (pages B-1 through B-19) is a memorandum prepared for the Sloan Commission on February 9, 1971, which was later revised on April 1 and again on May 26, 1971 on the basis of comments by Rediffusion personnel. The May 26th version was included as Appendix B when this final report on the M.I.T. study was originally submitted to the Sloan Commission on June 7, 1971.

Two months after the submission of the report, further information was received from Mr. R. P. Gabriel, the Chairman of Rediffusion, Ltd., (letter dated August 10, 1971) and from Mr. R. W. Lawson at Dennis Port (letter dated August 24, 1971) which revised the cost data for almost every system component included in the original analysis. The net result is a reduction in the estimated per-subscriber cost from $256 to $186. This change has been made in the body of the report (Chapters II and III), and in the Sloan Commission's report "On The Cable, The Television of Abundance", released in December, 1971.

Rather than rewrite this appendix on the basis of these revised cost estimates, it seemed better to maintain both sets of figures for comparison. The second, added part of this appendix (pages B-20 through B-23) thus represents the latest estimate of component and system costs (as provided by Rediffusion in August, 1971), cross-referenced with the original text.

ELECTRONIC SYSTEMS LABORATORY
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

MEMORANDUM SLOAN-1B

The Rediffusion Switched
TV Distribution System

John E. Ward
February 9, 1971
(Revised April 1, 1971, and May 26, 1971)

I. INTRODUCTION

This memorandum presents a description and cost analysis of the "Dial-a-Program" cable TV distribution system being actively promoted in the U.S. market by Rediffusion International, Ltd., a London-based company. The system was first announced in several papers published in 1968, and was demonstrated in the U.S. and Great Britain in mid-1969 and early 1970. Subsequently, arrangements were made with Mr. Richard Leghorn, the owner of Cape Cod Cablevision in Hyannis, Mass., to make an experimental installation in Dennis Port, Mass., for which he held an unexercised franchise. Installation got under way in April, 1970, and service began in August, providing 12 program channels taken off the Hyannis cable system, plus additional experimental channels. There are presently 122 subscribers connected (January, 1971).

I visited the Dennis Port installation on January 19, 1971 and was cordially received by Mr. H. F. Goodwin, Commercial Manager, and by Messrs. John M. Gower and Ronald W. Lawson, Senior Systems Engineers. They were most patient in showing me the complete installation and its operating features, and in answering many questions on technical details and component costs. Information gained in this visit, plus that gleaned from several publications, was the basis for the original memorandum. These revisions are based on later information on cable installation costs, and comments received from Mr. Lawson in a letter dated May 10, 1971.

II. BACKGROUND

Rediffusion International, Ltd. has had many years of experience in Great Britain in radio and TV distribution over twisted-pair cables, using "HF" cable frequencies in the range from 0-10 MHz. In their British installations, the trunks, feeders, and subscriber drops carry each TV and radio program (up to six of each maximum) on a separate wire pair, and each subscriber has a manual selector switch. The TV picture carrier used is 5.9 MHz (or 8.9 MHz) and both TV and radio sound signals are carried at baseband at a level sufficient to drive a loudspeaker without amplification.

For those subscribers with a standard TV set, a fixed-frequency inverter translates the selected TV channel from the HF transmission frequency to a convenient VHF channel frequency (the TV receiver is left tuned to this frequency) and the video signal is recovered in the TV set in the normal way. The baseband audio signal directly drives the speaker through a volume control (requiring a special connection into the receiver). There is also apparently substantial use in Great Britain of simplified TV receivers without VHF tuners. In these "wired" receivers, the HF picture carrier is simply amplified and detected to recover the video signal.

In the United States, with its many TV channels, the above distribution system using a wire-pair per channel with home selection would be uneconomic. There is also interest in Great Britain in expanding the number of available channels. Rediffusion has thus come up with the "Dial-a-Program" concept in which a single HF distribution channel is brought to each subscriber and program selection of up to 36 channels is performed in a remote switching exchange under subscriber control via a telephone-type dial. This of course implies a hub-type network between the switching exchange and the subscribers, as opposed to the tree structure used by Rediffusion in Great Britain and by the present VHF CATV distribution systems in the United States.

This hub-type switched network has a number of potential advantages over the tree-structured VHF distribution system when considered in the context of the many proposals for advanced communications services in the "wired city" of the future. Among these are the ability to expand the number of subscriber program channels without limit by simply enlarging or cascading the selector switches in the exchange, the ability to set up the switching so that privileged information (e.g., medical news) can be seen only by selected subscribers, the demonstrated capability (in the Rediffusion system) for simultaneous "upstream" TV transmission using a 15-MHz vision carrier on the signal pair of any subscriber cable, and the many possibilities for two-way, narrow- or medium-band communications services using either or both of the unique wire pairs for each subscriber (a subscriber cable actually consists of four wires; a signal pair, and a control pair for program selection).

There are also a number of disadvantages as compared to present VHF systems. Among these are the more complex cabling of a hub-type network, the fact that each TV set to be used independently requires a separate cable and exchange switch (not just each household), the initial cost and maintenance problems of the switchgear, and the need for dispersal of switching locations roughly every one-third mile throughout the served area because of the 1800-foot length limitation on the unamplified subscriber cables. Actually, the use of remote switching locations aids the hub-type cabling problem by limiting the number of subscriber cables brought to any one hub, but real estate must be found and purchased or leased for each of these many remote switching installations.

The relative balance of the above advantages and disadvantages vis-a-vis those of VHF tree networks is of course of great interest, particularly in any attempt to predict the most desirable type of system to provide some of the communications services which have been postulated for a decade or two hence. The present memorandum does not attempt to strike such a balance, but provides an input to such an evaluation by documenting the technical features and cost data for this particular system.

III. THE DIAL-A-PROGRAM SYSTEM

The following describes the novel technical features of the Rediffusion system, including the special distribution cable, the program switching exchange, and the present and possible two-way communications services.

A. Distribution Cable

As previously described, the heart of the Rediffusion approach is the transmission of TV signals in the high-frequency (HF) region of the frequency spectrum (2-15 MHz rather than at the VHF frequencies (50-240 MHz) at which they are carried on conventional cable systems. Rediffusion also calls this "Super Video" because of the small frequency translation (7.94 MHz) of a baseband 6-MHz video signal to produce their HF signal. The advantage of using such low transmission frequencies is that it permits use of twisted-pair wires in place of the coaxial cable needed at VHF frequencies. It is well known that standard telephone cable pairs have a usable frequency range (limited by attenuation) up to about one MHz, which is the bandwidth of Picturephone signals. Rediffusion has designed special twisted-pair cables which have an attenuation in the 2-15 MHz region comparable to that of coaxial cable at VHF frequencies; about 2 dB per 100 feet.

The Rediffusion distribution circuit actually consists of four wires twisted together — what they call a Qwist™ — with two of the wires forming a signal pair and the other two, interdigitated with the signal pair, serving as a control pair. The 25-gauge signal pair has a usable frequency range of 0-15 MHz, and the 26-gauge control pair is usable from 0-1 MHz. Special attention must be paid in manufacturing to produce this performance, but present cable costs are not unreasonable (see below).

The Qwist cable is produced in two versions: a one-way cable (one Qwist) used for house drops, and a six-way cable (six Qwists in one sheath) used for feeders from the switching exchange. These cables are produced by several British manufacturers in both screened and unscreened types, with the former having a copper tape shield. Both types are jacketed in a conducting polythene sheath. The unscreened type, which is less expensive, is used in underground runs or in aerial runs where interference pickup is not a problem. Where pickup is a problem, the shielded type is used. Adjacent-channel coupling was of course a problem in the six-Qwist cable since the Qwists are in physical contact, but the cable has been carefully engineered (for example use of different twist pitches on adjacent Qwists) to keep cross-coupling below -46dB in the longest cable run. The outer diameter of the six-way cable is about 3/8", and in practice seven of these are laid together to form a 42-circuit bundle 1 1/4" in diameter. Discussions are under way with several United States manufacturers for production of these cables.

The present costs of Qwist cables (without U. S. duty) are as follows:*

Six-way Unscreened	$125.00	per 1000'
" Screened	172.00	" "
One-way Unscreened	31.50	" "
" Screened	77.00	" "

There is thus a cost advantage in running as much as possible of the distribution in the six-way cable, since the per-subscriber cost is then $21.00 and $28.50 per 1000 feet for unscreened and screened cable, respectively.

The six-way cable attenuation is 1.4dB per 100 feet at 10 MHz, and maximum run of this cable from the exchange to a subscriber is 1500 feet, set largely by the maximum allowable attenuation (21dB) and partly by the maximum permitted "crossview" between adjacent cable pairs (-46dB). Individual drops on one-way Qwist may extend 300 feet beyond this (or up to five miles with single-channel repeaters at 3/4-mile intervals, but the repeaters cost $61 each). Except for occasional isolated houses, an attempt would be made to site exchanges so that all runs would be less than 1800 feet and therefore not require amplifiers.

Interexchange trunks in the Rediffusion system use a separate coaxial cable for the HF composite video (7.94 MHz picture, 3.44 MHz FM sound) of each program channel, and telephone-type wire pairs for the associated baseband sound signals. The composite video and baseband sound signals are separately amplified in each exchange (thus avoiding any possibility of cross-modulation) and mixed for application to the exchange busbars. At HF, the 0.3-inch coaxial cables used for the trunks have an attenuation of only 40dB per mile, so no line amplifiers are needed between exchanges, which are generally located about 1/3 miles apart.

Rediffusion quotes a cost of six cents a foot for the coaxial cable used in the trunks, and one cent per foot for the audio twisted pair (in 12-pair

*See later (August, 1971) figures on page B-20.

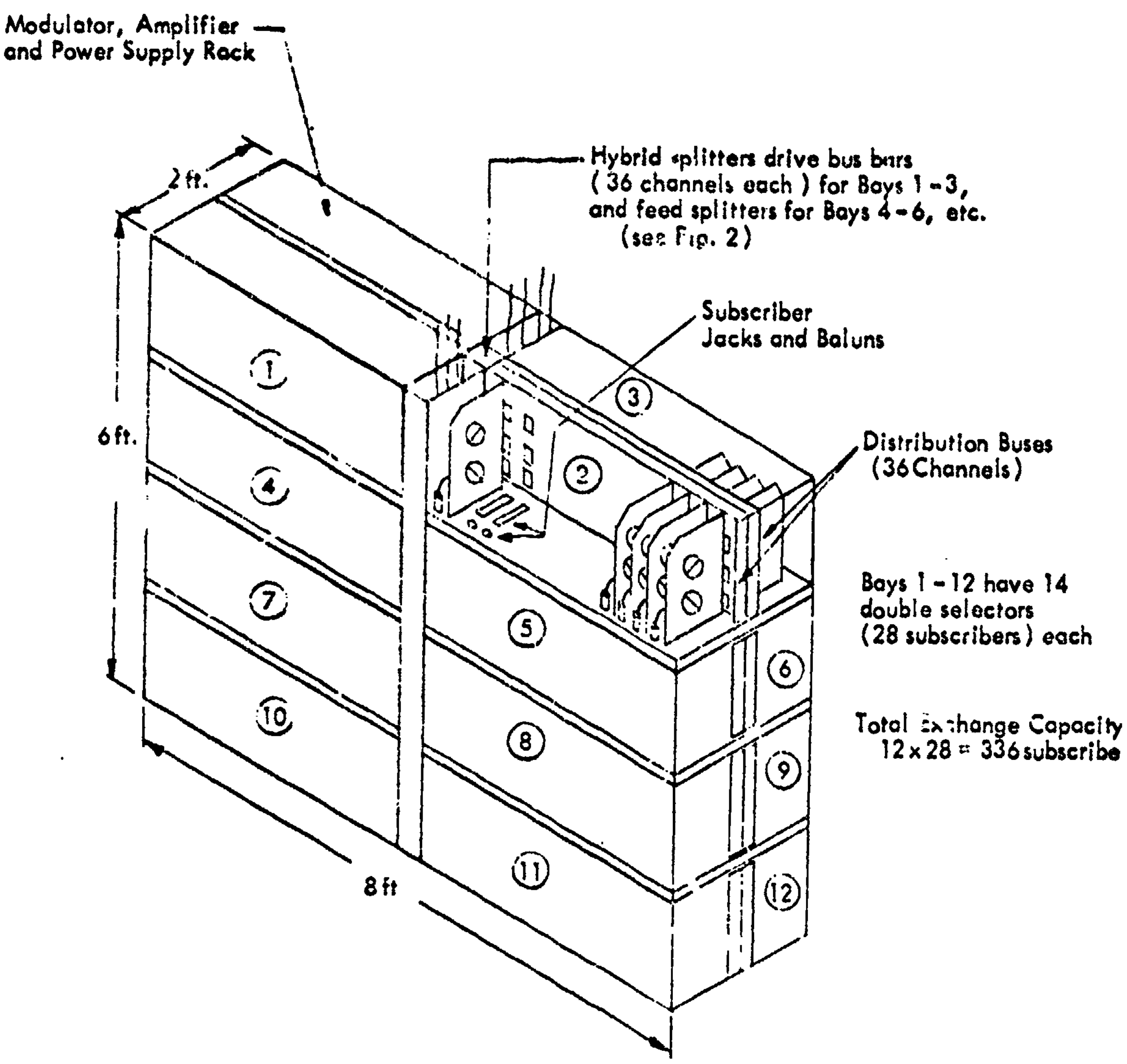
cables). Cable costs for a 36-channel trunk are thus relatively high — $13,306 per mile, plus installation.

B. The Program Exchange

Rediffusion has apparently settled on 336 subscribers as the best size for a program switching exchange, although no justifications for this choice are given. To some extent, this size seems to have been arrived at both from practical considerations in switch design (see below), and from the fact that the service area of an exchange is limited to 1/5 square mile or less by the 1800-foot maximum length of subscriber cables. Some of the Rediffusion documents discuss ten exchanges (3360 TV sets) per square mile as a typical installation plan. For very high-density areas, either the 336-size exchanges could be installed in multiples, or larger exchanges may be planned (in his IEEE paper*, R. P. Gabriel states that an exchange for 5000 subscribers would require a room 27 by 15 feet, but does not discuss its implementation). The following describes the present 336-subscriber switch as installed at Dennis Port.

The exchange is designed around a rotary, 36-pole switch of novel design. Thirty-six reed switches are arranged in radial configuration and are activated one at a time by a magnet on a rotatable selector arm. The arm is driven by a solenoid-driven ratchet that responds to subscriber dial pulses. Two of these switches are mounted on a printed-wiring card 9 x 15 inches in size, which plugs into the exchange distribution bus as shown in Fig. 1. The printed wiring is laid out with alternate wires at ground potential for shielding, thus three 24-pin connectors are used on each card for the 36 channels and associated grounds. Even with this shielding, there can still be some coupling between lines on the cards and in the busses and Rediffusion has provided for use of vision-carrier offsets of 5244 Hz (one-third the horizontal scan frequency) between alternate lines in the event of any problem with visible beats between programs (they have not had to use this at Dennis Port). This would also aid in reducing visibility

* "Dial-a-Program — an HF Remote Selection Cable Television System," R. P. Gabriel, Proceedings of the IEEE, July, 1970, pp. 1016-1023.



Note: The above represents an eventual packaged configuration. At Dennis Port the switch frame is as shown but there are several additional racks of "head-end" signal processing equipment needed to convert Cape Cod Cablevision VHF channels to the rediffusion HF channel frequency.

Fig. 1 Mechanical Configuration of a 336x36 Program Exchange of any beats with the second harmonic of the sound carrier, which appears at 6.88 MHz.

The distribution busses also use stripline techniques, and each bus can accommodate 14 switch cards. As shown in Fig. 1, the exchange is arranged in two sets of back-to-back racks, with the bus feeds in the center. Three of the racks hold four bays of 28 switches each, and the fourth bay contains the amplifiers and other electronic equipment.

Figure 2 shows the signal distribution scheme in the exchange. One of the problems was to avoid interactions between subscriber lines, i.e., signal level changes as a function of subscriber load on a particular program. This seems to have been successfully accomplished, since it is stated that signal levels are maintained within 1 dB for 0 to 100 percent of the subscribers choosing the same program. Also a short on any subscriber line causes only a 1/2 dB reduction in bus signal level — other subscribers are not affected.

Note that the signal level decreases 24 dB between the first and last banks of switches, and that a subscriber must therefore be assigned to a switch bank on the basis of his cable length from the exchange. It is apparent that careful planning and balancing of the cable network is required for each particular area served. Also, if an exchange were to serve say just one large apartment building (which could have 336 TV sets), there would not be a 24-dB variation in cable loss between the nearest and farthest subscribers, and attenuators would be required in many of the subscriber lines.

The busses and selector cards of the present exchange are designed for a maximum of 36 channels. Rediffusion states that 72- or 108-channel systems are easily obtained, but it is not easy to see how they would do this except by paralleling exchanges, each with 36 different channels, and assigning a selector in each exchange to each subscriber. Present 336 by 36 exchange equipment costs (see Section IV) work out at $75 per subscriber, or roughlv $2.00 per channel per subscriber. Assuming parallel exchanges, 72- and 108-channel systems would have exchange costs of about $150 and $225 per subscriber, respectively.

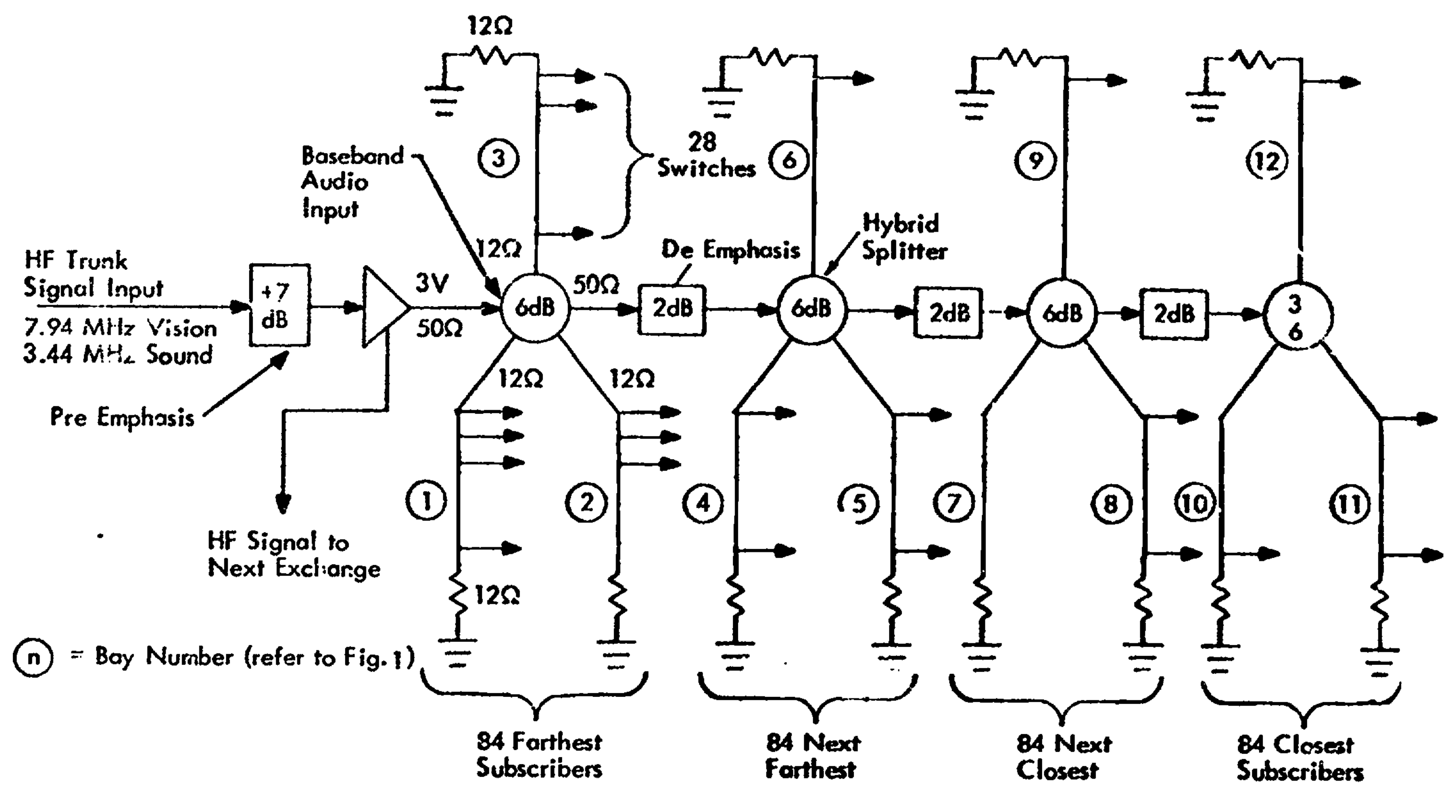


Fig. 2 Signal Distributions in 336 Subscriber Exchange (Typical of each of 36 Channels)

C. Operational Features

Each subscriber is provided with a combination HF/VHF inverter and control unit the size and shape of a 500-series dial telephone without the handset. This unit is connected to both the incoming Qvist cable and to the antenna terminals of the TV set, and is usually installed with wires long enough that it can be conveniently carried around the room for armchair program selection.

The dial uses one of the two control wires to operate the subscriber's selector switch in the exchange on an incremental basis; that is, each dial pulse advances the ratchet one position. A subscriber can thus quickly step through all the channels by dialing successive "1's". For dialing a desired line directly, the subscriber first pushes a reset button which uses the second control wire to operate a homing solenoid that returns the selector to channel 0, where a channel directory card is shown (by means of a camera at the exchange). He then dials the desired number. Because of the incremental nature of the dial system, channel 10 is reached by dialing 0, 11 by 01, 33 by 0003, etc. It is also possible with a little mental arithmetic to dial only the difference between the present and any greater channel number without going through the reset cycle, i.e., dialing 7 will advance the selector from channel 6 to channel 03 (13). Note however that there is no indication of what channel number is currently selected.

The present dialing at Dennis Port is rather convenient since there are only 14 channels in use — one program directory, 12 Cape Cod cablevision, and one local origination. This latter is a static camera in a delicatessen which shows their special-of-the-day, primarily to demonstrate the two-way capability of the system. With these few channels, only two digits are required in direct dialing, but even so, many subscribers apparently prefer to step through one at a time. Dialing would be less convenient for a full 36-channel system, since it takes about 10 seconds to push the reset button and dial 0005, or 30 seconds to step through 36 channels one at a time. It would seem that Rediffusion may eventually want to go to a digit-decoding dial system, particularly if channel capacity is increased to 72 or 108 channels.

I was also shown the channel lock-out feature, which is accomplished quite simply by clipping small magnetic shields over the selector reeds which are to be disabled for a particular subscriber. Alternately, the reeds can be removed (or not installed). This could be used, for example, to permit access to a medical news channel only by doctors, or to set up easily changed private, two-way TV networks for the police, and so forth.

D. Two-Way Capabilities and Potentialities

As previously mentioned, the frequency band between 9.2 and 15.2 MHz on any subscriber cable can be used for simultaneous upstream TV transmission; what Rediffusion calls "program injection". To use this capability, hybrids and filters must be inserted in the cable at both the subscriber and exchange ends to prevent signal interactions. A camera and modulator may then be plugged in at the subscriber end, and its signal picked off at the exchange end. One use which was demonstrated is to demodulate the received signal, remodulate it at the distribution frequency and put it on an unused bus for viewing throughout the network. Thus local origination from any point in the network is quite convenient. An interesting maintenance and troubleshooting aid results from this capability — a portable camera can be pointed at a subscriber's receiver, and the receiver pictures monitored at the exchange as the selector is stepped through manually.*

No provisions exist at the moment for connection of an injected signal to any other subscriber except through a distribution bus of the exchange. Also, the necessary hybrids, filters and modulators are installed on only two lines for demonstration purposes. Although the transmission capability for private two-way TV links could be obtained by fitting all lines, the

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* It should be noted at this point that a similar subscriber injection capability can exist in any VHF tree-structured system that is equipped for upstream channels. One important difference is that in a VHF cable, there are a limited number of upstream channels shared among all subscribers (four per cable if only sub-band is used, perhaps 30 if a separate upstream cable is used). Also, it would be difficult to prevent clandestine monitoring of upstream transmissions in a tree-structured system since the cable would be readily accessible to all subscribers between the injection point and the head end. Note that there is an additive noise problem in transmitting upstream in tree-structured systems, but it is assumed that this will be overcome.

switching capability for subscriber-to-subscriber connections on a general basis does not exist and its implementation with the present types of switch cards would require expansion and a completely different organization of the exchange.

Rediffusion also stresses the availability of one or both wire-pairs for other two-way uses such as meter reading, voice links, subscriber response to programs, and so forth. One possibility which they mentioned is to shift the present d-c control functions to the signal pair, leaving the 1-MHz control pair completely free for other uses. Here again, additional switching would have to be added to the exchange to make use of these lines in any way. The interesting question to be answered is the relative difficulty and cost of adding such capability, as opposed to obtaining similar capability in a tree network (VHF cable) by time-division multiplex techniques.

IV. COST DATA

Rediffusion has published a schedule of Provisional Prices, dated September 15, 1970, which gives detailed costs for items of head-end equipment, the equipment items needed in a remote exchange, the per-foot cost of cables for trunks, feeders, and drops, and the cost of each subscriber control unit. From this it is apparent that head-end equipment (except for antennas and low-noise preamps) works out at about $1000 per channel, roughly comparable to that of VHF head-end equipment.

What is of more importance in any comparison with VHF systems is the per-subscriber cost of a sub-unit of the distribution system: a local exchange serving 336 TV sets, its trunk connection, and the distribution cabling, junction boxes, and control units. The Rediffusion literature has example equipment costing for 12-channel systems, but it was of more interest to examine a 36-channel system.

A. Exchange Equipment

The following lists equipment needed for a 336 x 36 exchange (note that the prices shown do not include U.S. customs duty, which might add 6-12 percent):

Switchframe and Busbars				$ 2,000
TV Repeaters	36	at	$105.50	3,798
Power Supplies	6	at	60.00	360
Sound Amplifiers	36	at	44.50	1,602
Power Supplies	4	at	60.00	240
Hybrids	6	at	123.00	738
Control Panels	84	at	20.00	1,680
Double Selectors	168	at	89.00	14,952
Total Exchange Cost*				$25,370

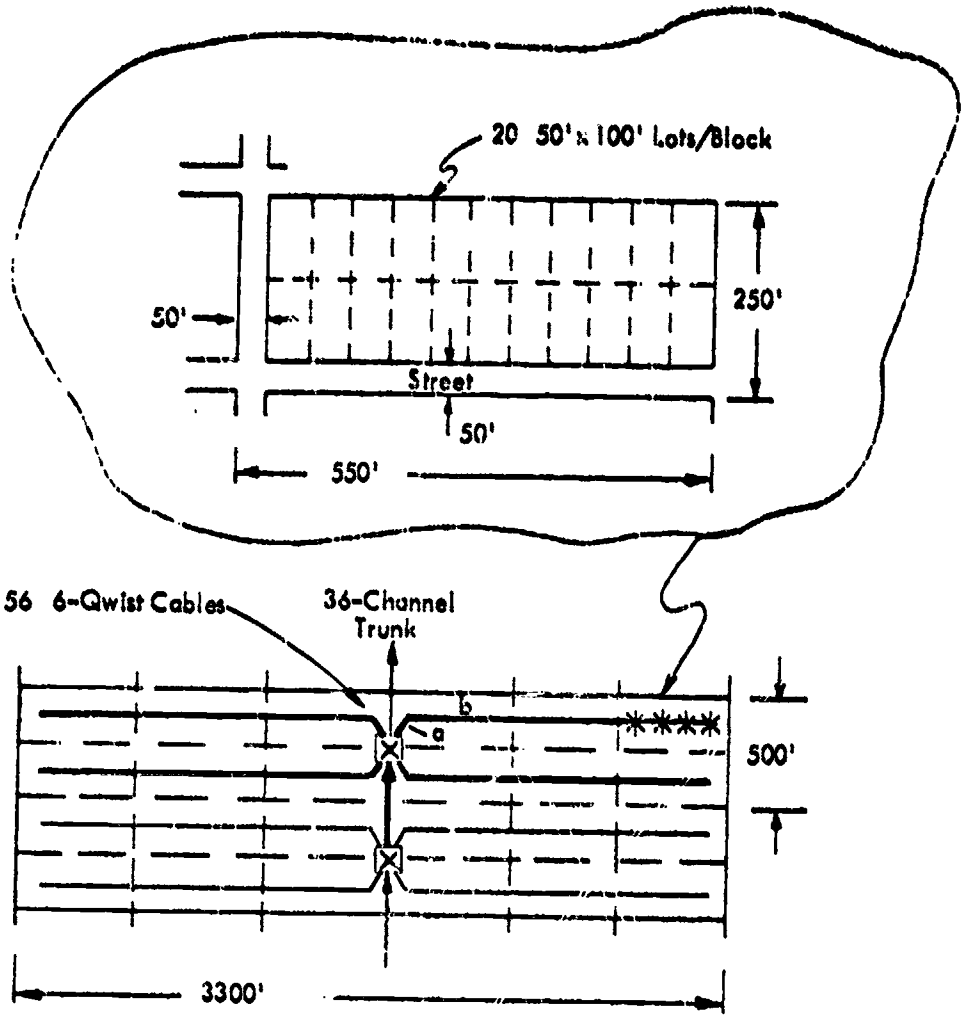
The per-subscriber cost of the exchange itself is thus $25,370 ÷ 336 = $75, without provisions for housing it and controlling its environment. If mounted outdoors (probable in suburban areas), a weatherproof kiosk would be used (estimate $1000), and 100 - 200 square feet of land would have to be purchased or leased. If mounted indoors (which it might be in urban apartment areas), space would probably be available without cost as it is for telephone company equipment on a user's premises. The exchange requires one kilowatt of electrical power (about $300 per year).

B. Cabling

For purposes of estimating cable costs, it is necessary to consider the type of area served and a typical cable layout. It is also necessary to remember that subscribers with multiple TV sets which they wish to use independently will have to have a separate selector and cable for each set, i.e., they will have to be multiple subscribers. Rediffusion has estimated that 40 percent of the subscribers will be multiple users, thus it is assumed that a 336-channel exchange can serve 240 households, 96 of which have two TV sets.

Figure 3 diagrams a typical block and street layout for a medium-density, single-dwelling area. It is assumed that lots are 50 by 100 feet, 20 to the block. Each exchange can thus serve an area 2 x 6 blocks (240 houselots) with an allowance for 96 multiple TV sets. The average length of the 56 6-Qwist feeders is

* Later Rediffusion data differs in detail, but yields the same total exchange cost (see page B-21).



Assumptions $a = 125'$

$b = 1650'$

Average Length of 6-Qwist $= a + \frac{b}{2}$

Fig. 3 Possible Exchange Layout in Medium-Density Single Dwelling Area

$$a + \frac{b}{2} = 125 + \frac{1650}{2} = 125 + 825 = 950'$$

and total 6-Qwist cable required is $56 \times 950' = 53{,}200'$.

It is assumed that single-Qwist housedrops will average 100 feet, thus single-Qwist requirements will be $336 \times 100' = 33{,}600'$. One junction box ($15) is required to connect a 6-Qwist to six house drops.

The total distribution cable and junction box costs for the layout of Fig. 3 would thus be (assuming shielded cable for aerial installation):*

6-Qwist - 53,200'	at	$ 0.172/foot	$ 9,150
1-Qwist - 33,600'	at	$ 0.077/foot	2,587
Junction Boxes - 56	at	$15	840
Total distribution cable cost			$12,577

This probably represents close to a maximum cost for distribution cable per exchange. Exchanges in more densely populated areas (apartments or two-family housing) would require less 6-Qvist cable because they would serve a smaller area. In suburban areas with larger houselots, the same length of 6-Qwist cables could fan out over a larger area. More single-Qwist (and perhaps line repeaters) might be needed in the latter case, however.

We must also figure in the cost of the trunk cable from the previous exchange as part of the sub-unit cost. In the layout of Fig. 3, the air-line distance between exchanges is 500 feet. Using the 36-channel trunk cost of $13,306/mile developed in Section III-A, and an estimated terminal-to-terminal cable length of 700 feet, trunk cable cost per exchange would be $1764. Note that there is a premium, as Rediffusion points out, on keeping trunk distances short because of the relatively high cost of trunk cables — $2.52 per foot for 36 channels.*

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*These figures valid as of May, 1971. For more recent estimates see page B-21.

The above figures pertain to cable purchase costs only. Good cost figures for the installation of Rediffusion cables have been difficult to arrive at. In one Rediffusion paper,* a labor cost of $1.60 per foot for trunk and feeder installation is given, without making it clear whether this applies to route-footage or to the total footage of individual cables, which is about ten times greater than the route footage. Thus in the original version of this memorandum, the geometric mean of these two interpretations was tentatively assumed for want of a better figure. This resulted in a labor-cost estimate of $70,000, which was felt to be high, but was somewhat supported by the indication in Mr. Gargini's paper that 2/3 of total remote selection costs are in labor and overhead for trunk and feeder installation.

Subsequently, the installation cost question was discussed with Mr. H. F. Goodwin of Rediffusion by telephone on February 19. He said that he also did not understand the basis for the $1.60/foot figure, in Mr. Gargini's paper, and kindly offered to prepare an approximate labor cost estimate for a specific layout. The exchange layout of Fig. 3 was described to him, and he called back a day later with an estimate of $30,000 for installation labor costs. He also furnished figures for cable and equipment purchase costs which agreed to within a few dollars with those derived above.

(Note added January 5, 1972: Subsequent to submission of this report, the $30,000 estimate for cable installation labor was reduced to $15,500 by Mr. R.W. Lawson in a letter dated August 24, 1971. For a 336-subscriber exchange, this factor alone lops off $43 per subscriber, more than half the net reduction in the latest Rediffusion per-subscriber cost derived on page B-22.)

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* "Dial-a-Program Communication Television," E. J. Gargini, paper delivered to the Royal Television Society, February 12, 1970, Figure 20.

C. Per-Subscriber Distribution Costs (May 26, 1971)*

From the figures which have been established, we now can sum up the total cost of installing a 36-channel Rediffusion exchange for 336 subscribers under the assumptions inherent in Fig. 3, and establish the per-subscriber cost:

Cable and equipment purchase (catalog prices)		
Exchange equipment	$25,370	
Qwist cables and junction boxes	12,577	
Trunk cable (36 coax plus 36 audio pairs)	1,764	
Subscriber control units (336 at $34)	11,424	
		$51,135
Installation labor (Rediffusion estimate)		30,000
Land and kiosk (M.I.T. estimate)		5,000
Total distribution cost per 336 subscribers	=	$86,135

The per-subscriber installation cost for the Rediffusion switched distribution system is thus $256.* Note that this does not include any share of head-end equipment costs (which should be pro-rated over all subscribers in all exchanges served by it), or any special installation costs such as make-ready charges on poles, etc. These omitted costs depend on total system size and local conditions, and tend to be about the same for any type of system.

As discussed in Section III-B, the program busses and rotary selector switches of the present exchange are designed for a maximum of 36 channels. Although some economies might be possible in a redesign for more channels, the incremental cost of doubling or tripling the number of channels can be fairly accurately estimated on the basis of adding an exchange and trunk for each 36 channels, with distribution cables and subscriber control units remaining the same. (One easy way to expand the control function without altering the present control unit would be to have the reset button cycle the subscriber's line through the channel 0's of the exchanges available to him. He could then read the channel listings for each exchange and dial the desired program in that exchange, or shift exchanges by pushing the reset

* For later estimates by Rediffusion, Ltd., see page B-22.

button again, etc.) On the above assumption, the total distribution costs for 72- and 108-channel systems might be:*

	72 Channels	108 Channels
Exchange equipment	$50,740	$76,110
Qwist cable and junction boxes	12,577	12,577
Trunk cable	3,528	4,292
Subscriber control units	11,424	11,424
Installation labor (estimate)	35,000	40,000
Land and kiosk (estimate)	7,500	10,000
Total for 336 subscribers	$120,769	$144,403
Per-subscriber cost	$360	$430

* These figures as of May, 1971. For later estimates by Rediffusion see page B-23.

V. ADDENDUM (December 27, 1971)

As stated on page B-1, revised cost data was provided to the author from two different Rediffusion sources during August, 1971, which resulted in a new per-subscriber cost figure of $186. Listed below are changes affecting particular pages of the original memorandum (new cost figures underlined).

Page B-6 (Revised Qwist and trunk cable costs)

Six-way	unscreened	$87.00	per 1000 feet
Six-way	screened	$117.00	" " "
One-way	unscreened	$21.00	" " "
One-way	screened	$42.00	" " "

"There is thus a cost advantage in running as much as possible of the distribution in the six-way cable, since the per-subscriber cost is then $15.00 and $20 per 1000 feet for unscreened and screened cable respectively."

(Mr. Gabriel also noted in his August 10 letter that by cable selection and use of small exchange amplifiers ($18 per line), a maximum subscriber distance of at least 2500 feet can now be achieved, rather than the former 1800-foot limitation.)

In regard to trunk cable, Mr. Gabriel now projects a coaxial cable cost of 2.5 cents per foot rather than the 6 cents formerly quoted. This reduces trunk cost (36 coaxial cables, 36 audio pairs) to about $6500 per mile instead of $13,306.

Page B-14 (Revised exchange costs)

Switchframe and busbars			$ 3,390	(not $ 2,000)
Selector power unit			158	
TV repeaters	36 at	$122.00	4,392	(not $ 3,798)
Power supplies	6 at	72.00	432	(not $ 360)
Hybrids - sets of 4 at $33.12	36 at	33.12	1,192	(not $ 738)
Control panels	168 at	9.36	1,572	(not $ 1,680)
Double selectors	168 at	72.00	12,096	(not $14,952)
Total Exchange Cost without audio		=	$23,232	
Sound amplifiers	36 at	55.00	1,980	(not $ 1,602)
Power supplies	3 at	72.00	216	(not $ 240)
			$ 2,196	
Total Exchange Cost with audio		=	$25,428	(not $25,370)

Page B-16 (Revised distribution cable costs for Figure 3)

6-Qwist	- 53,200 feet at	$ 0.117/foot	$6,210	(not $ 9,150)
1-Qwist	- 33,600 feet at	$ 0.042/foot	1,412	(not 2,587)
Junction boxes	- 56 at	5.00 each	280	(not 840)
Total distribution cable cost		=	$7,902	(not $12,577)

Page B-18 (Revised per-subscriber distribution costs)

Cable and equipment purchase

Exchange equipment	$23,232	(not $25,370)
Qwist cables and junction boxes	7,902	(not 12,577)
Trunk cable (700 feet)	864	(not 1,764)
Subscriber control units	10,416	(not 11,424)
		$42,414
Installation labor (Rediffusion now estimates $15,500 instead of $30,000)		15,500
Land and kiosk		5,500
Total distribution cost per 336 subscribers		$62,914

This is equivalent to a per-subscriber cost of $186, compared to the $256 derived previously.

Pages B-18 and B-19 (Revised estimate of expanded system costs)

Rediffusion has now stated that they would parallel exchanges as follows:

> "Our proposals for increasing the program capacity of the exchange involve the use of a number of exchanges with a selector. For example, for 72 channels we would have two complete 36 program exchanges preceded by a change-over switch which would respond to the first digit dialed. For 108 or more channels we would have a multi-channel selector using reed switches working on the same principles as the existing selectors and serving to select whichever 36 program exchange was carrying the desired program. We have so far made no attempt to work out the design in detail and I have made a wild guess at the costs. The extra installation required for 72 or 108 channels is mainly the addition of 36 channels on the trunk routes, i.e., the pulling in of a multi-coaxial cable into existing ducts. There will also be some additional labour in the installation of the exchange equipment but we intend that this equipment should be delivered in complete packages requiring the minimum of installation and I feel, therefore, that the additional installation labor per 36 channels is about $2000, rather than $5000. With these amendments the figures appear as follows:

	36 Channels	72 Channels	108 Channels
Exchange pre-selector	-	$ 3,360	$ 5,000
Exchange equipment	$23,232	46,464	69,696
Qwist cable and junction boxes	7,902	7,902	7,902
Trunk cable	864	1,728	2,592
Subscriber control units	10,416	10,416	10,416
Installation labour (estimate)	15,500	17,500	19,500
Land and kiosk (estimate)	5,000	7,500	10,000
Total for 336 subscribers	$62,914	$94,870	$125,106
Per subscriber cost	$187 (not $256)	$283 (not $360)	$374 (not $430)

In the conclusion to his letter, Mr. Gabriel states: "I feel I should point out that the per subscriber costs which have been derived above are under the most favourable circumstances of 100 percent penetration and all exchanges fully loaded. One might hope to get fairly near this condition in a planned community. In the more usual situation there is bound to be some redundancy either of pairs in the cables or of unused exchange positions. Without more practical experience with the system I could not make any estimate of the extent of this."

APPENDIX C

The AMECO DISCADE
Switched TV Distribution System

This appendix consists of a revised version of a previously distributed memorandum. The revisions include corrections suggested by AMECO following its review of the original memorandum.

ELECTRONIC SYSTEMS LABORATORY
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MEMORANDUM SLOAN-2A

The AMECO DISCADE Switched TV Distribution System

John E. Ward
March 24, 1971
(Revised May 18, 1971)

I. INTRODUCTION

Ameco, Inc., Phoenix, Arizona, is making installations of a switched, sub-channel TV distribution system of its own design in Daly City, California, and at Disneyworld, Florida. Although the basic principle of this system is quite similar to that of the Rediffusion "Dial-a-Program" system which was analyzed in Memorandum Sloan-1, there are significant differences in system implementation which affect both the installation requirements and the per-subscriber costs. It was therefore felt that a comparable analysis should be made of the DISCADE system in order to have the best possible basis for comparison of switched versus non-switched systems.

Preliminary information on the technical features of the DISCADE™ system (DIScrete Cable Area Distribution Equipment) was provided by an informal writeup (dated Feb. 1, 1971) obtained from Ameco in mid-February. In order to clarify a number of details which were not evident in the writeup, and to obtain cost data, I visited Ameco on March 3, 1971, where I met with Mr. Bruce Merrill, President, and Mr. Earl Hickman, Chief Engineer. They were most cooperative in answering all my questions and in discussing and/or demonstrating all the hardware used in their system. The revisions to the original memorandum are based on comments received from Mr. Merrill in a letter dated April 29, 1971, and primarily concern minor corrections to frequency capabilities, channel assignments, and cost estimates for sub-trunks and drops.

II. TECHNICAL FEATURES

The DISCADE system has been developed as a means of providing 20-40 usable channels while avoiding: (a) the on-channel interference problems of VHF-distribution, and (b) the harmonic, oscillator-beat, and image problems that can arise in the use of mid- and super-band channels. It was obviously influenced by the earlier Rediffusion system, but also has its roots in previous Ameco experience in sub-channel transmission techniques to avoid ambient signal interference in links between CATV antenna sites and their associated head-ends. DISCADE represents an alternate engineering solution to the design of a switched distribution system which appears to have a number of advantages over the Rediffusion system. On the other hand, it has the same primary disadvantage--that a household with multiple TV sets to be used independently must be a multiple subscriber. DISCADE utilizes coaxial cables throughout.

A. Trunks

Trunks in the present design are made up of eleven sets of cables and amplifiers designed for 5-50 MHz transmission, of which ten carry 2-4 TV channels each, and one carries the FM band, block-converted to 20-40 MHz from its normal 88-108 MHz region in the spectrum. Because frequencies no higher than 50 MHz appear on a trunk cable, smaller cable may be used than in usual practice, and amplifiers may be more widely spaced. For example, with .412" cable, amplifier spacing is 4,000 feet and trunk lengths up to 25 miles are feasible. These figures double if .750" cable is used, i.e., 50-mile trunks are feasible. Trunk amplifier assemblies are 10" x 7" x 22" in size, and the 11 amplifiers are modular, plug-in assemblies, designed so that any cable may be changed to upstream transmission by simply inverting its amplifiers when plugging them in.

For a 20-channel system, Ameco has used two channels per cable, choosing ones that are non-adjacent and not harmonically related, but both of these conditions can not be met in a 40-channel system. For example, at Daly City the two initial channels (22-28 MHz and 34-40 MHz) are neither adjacent nor harmonically related. If there is a requirement in the future to expand this particular system to 40 channels, Ameco has already verified that it is possible to add 5-11 MHz (note that use of frequencies between 11 and 22 MHz could create harmonic problems) and 28-34 MHz (adjacent to both the original channels). Such additions require no changes to the cable distribution system--only expanded head-end and subscriber selector equipment. For a new system with 40-channel capability initially, Ameco feels that they might use 24-48 MHz. These channels would all be adjacent, but not harmonically related. Another growth possibility mentioned is to keep two channels per cable but install more trunk and sub-trunk cables and larger switches, but this would increase costs linearly with added channels.

Ameco gives an approximate installed cost for 11-cable trunk of $11,000 per mile, of which about 35 perce is labor.

B. Sub-Trunks

Sub-trunks are connected to the trunk by sets of bridger amplifiers, each of which will drive the corresponding cables in four sub-trunks. An unusual feature of DISCADE is that the sub-trunk cables carry different signals than the trunk cables. As shown in Fig. 1, one of the functions of the bridger amplifier assembly is to block-convert the 20-40 MHz FM radio signals on the FM trunk cable to their correct frequency band (88-108 MHz) and add them to each of the ten sub-trunk cables. The sub-trunk cables thus carry both TV and FM signals, and all parts of the sub-trunk and subscriber distribution systems are designed for 5-120 MHz. Sub-trunks typically use .240" cable and are not amplified, but may be divided by means of passive splitters. Ameco gives an approximate cost figure for installed sub-trunk of $7,500 per mile, including the Area Distribution Centers (without switch modules) described in Section C below.*

C. Subscriber Switching

The main component of the DISCADE system is the Area Distribution Center (ADC) which is a cable-mounted switching unit, presently designed in sizes for 8, 16, or 24 subscribers. As many as ten ADC's may be spliced into each sub-trunk either at initial installation or later, as needed to meet subscriber hook-up requirements. Standard CATV-type drop cable is used to connect a subscriber to an ADC, and drops may be up to 2,000' in length.

*This estimate is for "reasonable density" and would vary somewhat depending on circumstances.

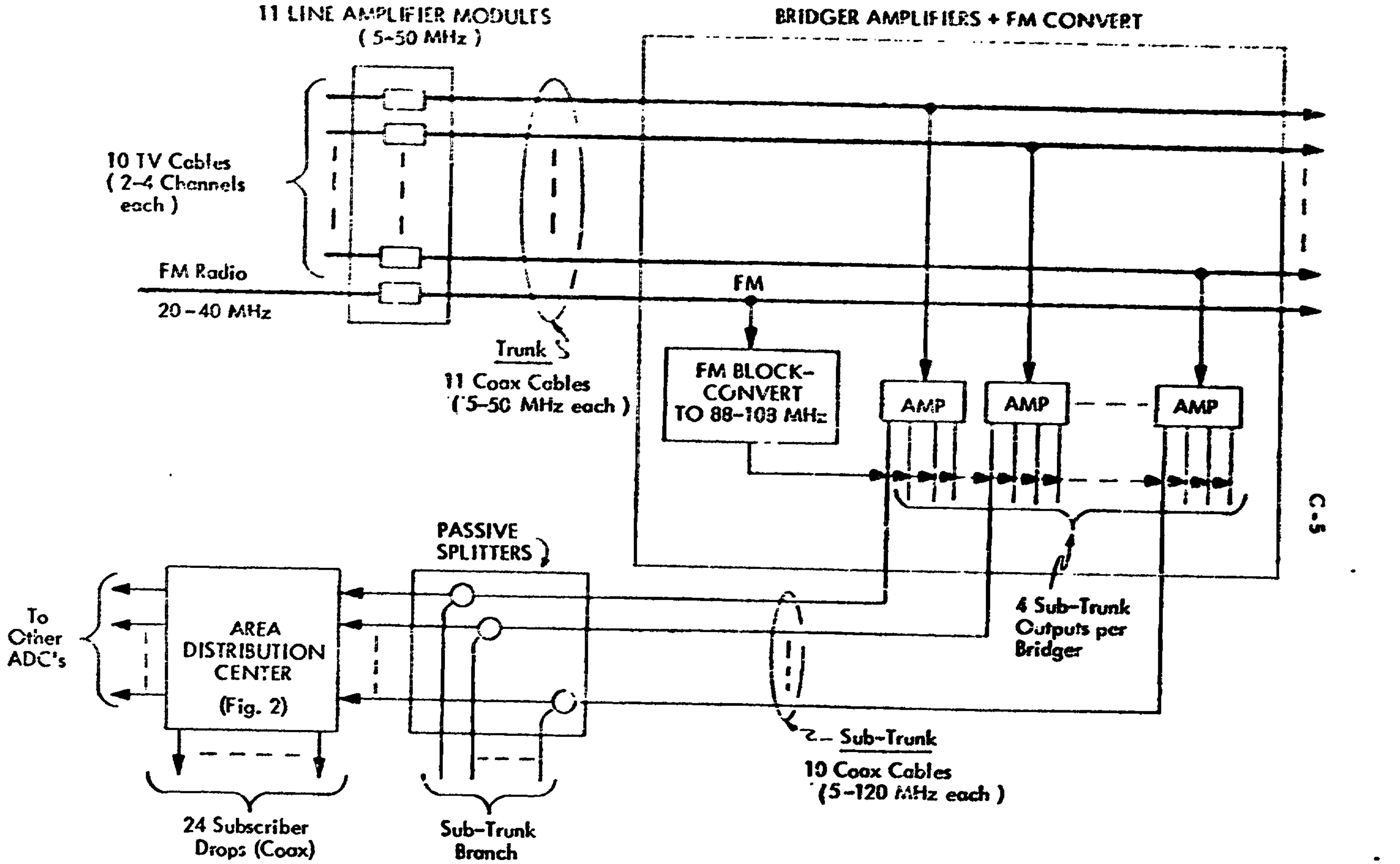


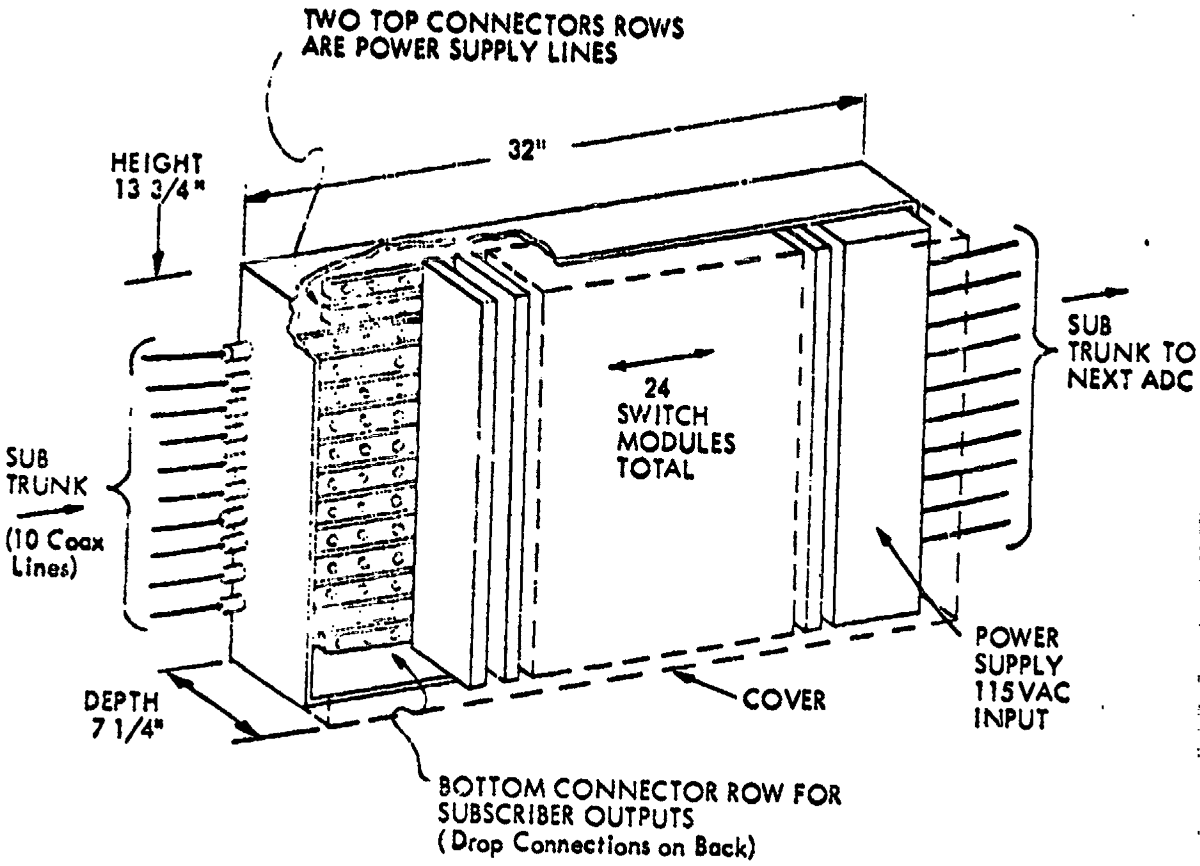
Fig. 1 AMECO "DISCADE" Distribution System

The physical configuration of a cable-mounted, 24-subscriber ADC is shown in Fig. 2. The switch modules are of solid-state design, and connect a subscriber drop to any one of the ten sub-trunk cables as controlled by direct-current pulses from the subscriber selector unit fed back to the ADC on the subscriber drop. An incremental form of control is used, with the switch advancing one position for each pulse (actually every other pulse, see discussion below). When cable number 10 is reached, the next pulse starts the sequence again at cable number 1, etc. The major cost item of the entire DISCADE system is the switch module which costs $60.00 per subscriber drop, but need only be installed as subscribers are actually connected.

Note that since the FM radio band is on all sub-trunk cables, it will appear on the subscriber drop no matter what position the switch is in, and will be unaffected by channel selection.

D. Subscriber Selector

The subscriber selector unit, which costs $15.00, is slightly smaller than a desk telephone, and has a click-stop rotary channel selector knob on top which sends a pulse to the ADC for each "click". A film strip coupled to the knob provides a very legible display of the selected channel number in large (3/4") illuminated numerals projected in a window on the front of the unit (this is a plus over the Rediffusion telephone-dial selection system, which provides no indication of what channel is currently being viewed). Because of the incremental-type switch control, the knob has a mechanical ratchet so that it can only be turned in the direction of increasing channel numbers, and there is no reset function like that in the Rediffusion system, except an automatic one on the transition from Channel 20 to Channel 1 which provides knob and switch resynchronization in case they should ever get out of step. Thus to go back one channel, the selector knob has to be turned several complete revolutions to cycle through all 20 (or 40) channels--a minor inconvenience.



Notes:

1. Size of 24-subscriber ADC = 7 1/4" x 13 3/4" x 32"
2. Weight of 24-subscriber ADC = 90 lb.
3. Sub-trunk loss per ADC = 0.5 dB
4. ADC provides power for subscriber selectors
5. ADC designed for cable mounting
6. Cost = $192/ADC housing plus $60/switch module and $15/subscriber selector
7. Each cable carries 2-4 TV channels plus FM radio (20-40 TV channels total)

Fig. 2 AMECO "DISCADE" Area Distribution Center (ADC)

The selector unit also contains two (or four) conversion oscillators, and as the selector knob is advanced, these are turned on alternately to convert one of the two (or four) channels available on the drop cable at each ADC switch setting to the clear VHF channel chosen for the TV receiver input. This combination of frequency and space switching sounds somewhat complicated, but is completely hidden from the user--all he sees is one dial labeled from 1-20 or 1-40, and the proper coordination of the cable switching and frequency selection takes place automatically as the selector knob is advanced.

As previously mentioned, the selector sends a pulse to the ADC for each knob "click", but the ADC switches cables only every second (or fourth) pulse. The reason for having a pulse sent to the ADC for each knob "click" is so that a channel-monitoring system could be implemented in the ADC if desired. Note however that since the selector unit is cable-powered, it works whether or not the TV set is on, and some means of also monitoring TV set power would be required for meaningful monitoring of channel viewing.

III. DISCADE INSTALLATIONS

Two different DISCADE installations are currently in progress,one using an interesting variation in the basic technique described above.

A. Daly City, California

Vista Grande Cablevision is installing a 20-channel DISCADE system exactly as described above in Daly City, with a potential system size of 16,000 subscribers. The main impetus for choice of this system by the operator was a firm requirement for 20 channels, plus an unusually severe local-signal problem--seven of the 12 standard VHF channels would be subject to ghosting from direct pickup. A field trial during 1970 with prototype hardware was entirely successful, but led to some equipment redesign to reduce costs. Installation of final hardware is now underway, and equipment sufficient for about 500 subscribers has been shipped to date.

B. Disneyworld, Florida

The Disneyworld installation will involve about 2,000 TV receivers and will be a 10-channel system with only one channel per cable. In this case, the set manufacturer (RCA) is incorporating a simplified Ameco selector unit designed to fit into the sets in place of the normal VHF-UHF tuner, and no frequency conversion is necessary in the selector because the signal on each sub-trunk cable is at the 45.75 MHz IF frequency of the receiver. The standard RCA motor tuning feature is retained, with its remote control unit.

IV. TWO-WAY CONSIDERATIONS

The DISCADE system as presently implemented does not incorporate any two-way features. It is not known what plans Ameco has for two-way use, but there are a number of possibilities.

As previously mentioned, one or more trunk cables can be converted to upstream transmission toward the head-end by simply reversing their line amplifier modules, providing 2-4 upstream channels per cable. If reverse bridger modules were developed to permit upstream transmission on one or more sub-trunk cables to feed into these upstream trunk cables, and any passive splitters were suitably modified, then these channels would be available at all switching units (ADC's).

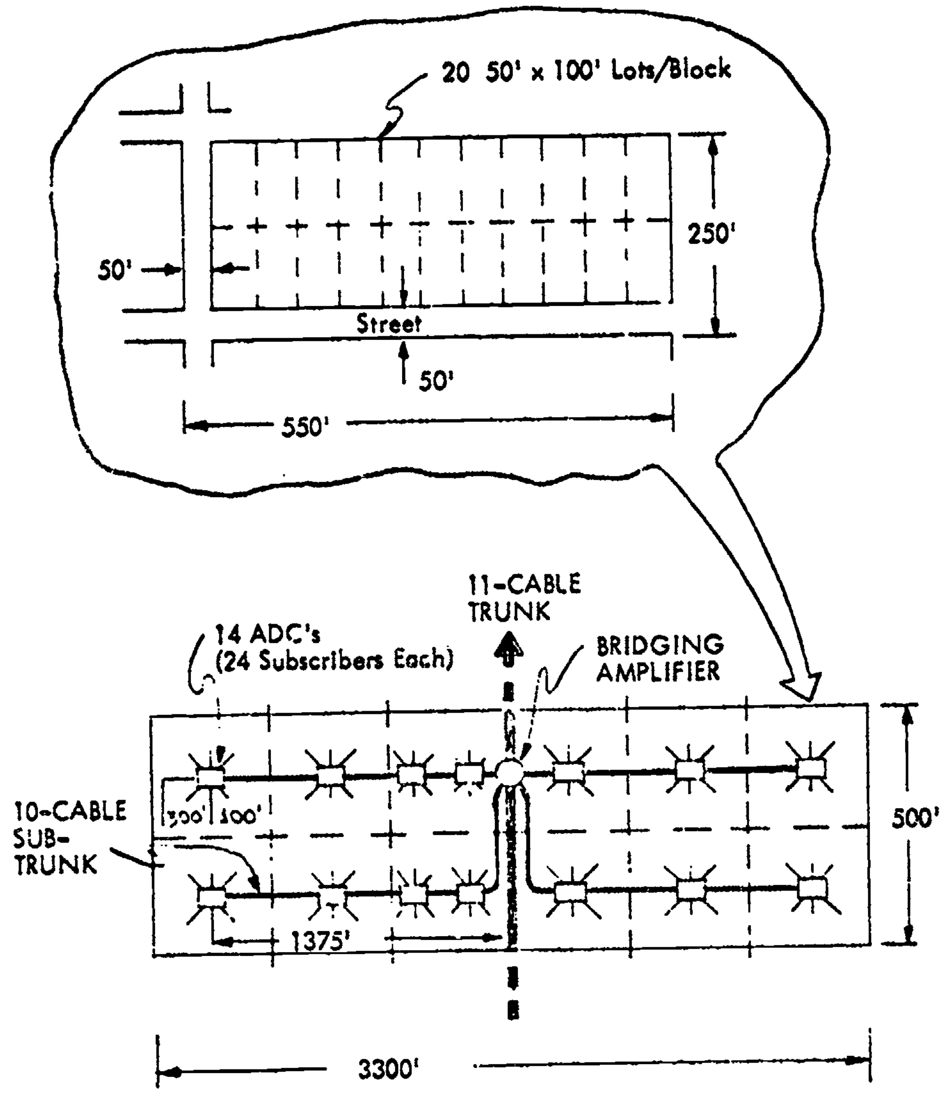
At this point, the way to proceed isn't as clear, but one would have several options for video origination. One option would be to simply make one or more switch positions be for upstream use only, essentially reversing the subscribers drop and permitting him to insert a video signal on one of the channels for transmission to the head-end. However, he then wouldn't be able to see anything at the same time. A second, and perhaps more attractive possibility would be to install a second, upstream-only drop for each subscriber that is not switched, but added to an upstream sub-trunk cable at the ADC along with all other upstream drops. This would permit simultaneous video origination plus viewing of any downstream channel for as many subscribers as there are upstream channels. A third possibility, which would require new types of amplifiers and perhaps switches would be to use frequency splitting techniques to permit bi-directional transmission on one or more cables. There are perhaps other possibilities. Either the second or the third schemes could permit one or two "videophone" conversations between any two points in the system, but these would be non-private.

Downstream and upstream digital transmission channels for a variety of uses (monitoring, meter reading, data, channel control, etc.) can also be established by various techniques such as the above. In this case the presence of the switch is somewhat of a hindrance because the polling equipment at the head-end would not know what cable to address a particular subscriber on unless it continuously monitored his switch. One possibility to avoid this complication would be to handle the downstream digital channel the same way as the FM band is handled at present, perhaps adding it to the FM trunk cable in the 16-20 MHz band so that it would always appear on all subscriber drops. Another would be to provide a separate, tree-structured bi-directional digital data cable which runs throughout the system. Here again, the above do not exhaust the possibilities, and Ameco's particular plans are not known.

In summary, DISCADE can be augmented to provide the same two-way capabilities as the non-switched systems at about the same incremental cost, but direct provisions for such augmentation are not readily apparent in the present hardware, except for the reversible line amplifiers and the switch-control design for eventual channel monitoring capability.

V. COST DATA

For purposes of relative cost comparison, the DISCADE system has been costed out for the same 12-block, 240-houselot unit area used in the analysis of the Rediffusion system in Memorandum Sloan-1. A possible DISCADE layout to provide 100-percent service to this area, with an allowance for 40-percent multiple subscribers, is shown in Fig. 3. As shown, it is assumed that one trunk bridging amplifier would drive four sub-trunks,



Notes:

Average Drop Length = $\frac{100 + 300}{2}$ = 200'

12 x 20 = 240 Houselots

14 x 24 = 336 Subscriber Capability (240 + 40%)

Fig. 3 Possible AMECO "DISCADE" Layout in same Unit Area used for Rediffusion Analysis each with either three or four Area Distribution Centers. The 40-percent multiple-set allowance would require 28 drops per block, thus the ADC's must be spaced not quite one block apart, and 14 are required in all to provide 336 total drop capability, the same as the Rediffusion exchange. Subscriber drops would range from 100 to 300 feet, or 200 feet average, and are figured at an installed cost of $.05 per foot (Ameco estimate). Trunk and sub-trunk installed costs are figured at the Ameco per/mile estimates given earlier. The distribution costs per unit area (as defined above) are thus:

Trunk - 500'	@ $11,000/mile	=	$1,050	
Sub-trunk - 6,000'	@ 7,500/mile	=	8,520	
Drops - 67,200'	@ .05/foot	=	3,360	
	Total Cable Costs	=		$12,930
Switch Modules	- 336 @ $60	=	20,160	
Subscriber Selectors	- 336 @ 15	=	5,040	
	Total Equipment	=		25,200
	Total Distribution Cost per 336 TV sets (not including head-end)	=		$38,130

This works out at $113.50 per subscriber for a 20-channel system, and would be little (if any) different for a 40-channel system, since only a minor change in the subscriber selector unit would be required.

APPENDIX D

METER READING VIA TELCO OR POWER LINES

Ultility companies have recently become interested in automating the process of reading utility meters. Two alternate systems under development have been investigated in an effort to determine what role the CATV cable could play in providing these or similar services.

The first system is being developed by Shintron* Co. to read electric meters using the power lines as the communications medium. The information is coded as a several millivolt signal carried directly on the power line. Since bit rates are very low (they are transmitting 0.05 bits per second) the small signals can be recovered from the much larger power signals by appropriate processing techniques. They use a single transmitter at the power station to service 2,000 installations, and control 25 transmitter units with a small computer which tabulates return data. The equipment required in the home can be largely fabricated in MOS integrated circuit form, and should fit inside an electric meter. Projected costs for the unit at the home are in the $20 to $30 range.

The second system is being developed by Bell Laboratories at Holmdel, New Jersey in co-operation with a number of manufacturers who have developed encoders for transmitting meter readings via the switched telephone network. A simple alerting circuit answers the meter reading request without ringing the customer's telephone. The coded readings are then converted into tone signals and routed through a telephone company central office to a data center serving one or more utility companies. This is done using a meter reading access circuit**

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* The information presented here was obtained from Mr. Larry Baxter of Shintron Co., Cambridge, Mass.; details of the system other than those given above are considered proprietary.

** R.E. Cordwell, P.J. McCarthy, "Communications Facilities for Automatic Meter Reading", a paper presented to the Power Distribution Conference, Austin Texas, October 20, 1970 in the telephone company office. The total time required to read the meter(s) in a customer's home is roughly 10 seconds. Thus 300 - 400 customers can be polled per hour.

The two systems presented are not designed to be expanded to provide any type of general-purpose digital communication service to the customer beyond the simple reading of utility meters, but are no less or no more costly than performing just this same function over a CATV cable. However, the meter reading task can be easily and cheaply integrated into an existing digital communications service, since the incremental cost of reading meters would probably be smaller than that for implementing a parallel system for reading meters. Note, however, that the inclusion of meter reading via the cable plant would require some sort of standardization of digital cable systems either at the meter interface or of the digital system itself. Note also that there would probably be little interest in reading meters via a CATV cable unless cable penetration (including two-way data capabilities) was virtually 100 percent in a given area. For some time to come, the power and Telco lines will reach more meter locations.